THE
METALLURGISTS AND CHEMISTS' HANDBOOK

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A REFERENCE BOOK OF TABLES AND DATA FOR THE STUDENT AND METALLURGIST

COMPILED BY

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Trigonometric Abbreviations

sin	sine	tan	tangent
cos	cosine	cot	cotangent
sec	secant	versin	versed sine
csc	cosecant	covers	coversed sine
$\sin^{-1}\theta$	angle whose sine is θ	$\sin\theta^{-1}$	$\frac{1}{\sin\theta}$

The Greek Alphabet

Α, α alpha	Ι, ι iota	Ρ, ρ rho
Β, β beta	Κ, κ kappa	Σ, ς, σ sigma
Γ, γ gamma	Λ, λ lambda	Τ, τ tau
Δ, δ delta	Μ, μ mu	Υ, υ upsilon
Ε, ε epsilon	Ν, ν nu	Φ, φ phi
Ζ, ζ zeta	Ξ, ξ xi	Χ, χ chi
Η, η eta	Ο, ο omicron	Ψ, ψ psi
Θ, θ, ϑ theta	Π, π pi	Ω, ω omega

Mathematical Constants

$e = 2.718281828459045$

$\log_e 10 = 0.434294$

$\pi = \frac{355}{113}$ (approx.).

$e = \frac{299}{110}$ (approx.).

$\pi = 3.14159265358979$

$\log \pi = 0.4971499$

$\sqrt{\pi} = 1.772$

$\log_e x = 2.302585 \log_{10} x$

$\pi^2 = 9.8696$

$\frac{1}{\pi_2} = 0.10132$

$\frac{1}{\pi} = 0.5642$

$\sqrt{2} = 1.4142136$

$\sqrt[3]{3} = 1.4422509$

$\sqrt[3]{2} = 1.2599210$

$\sqrt{5} = 2.2360680$

$\sqrt[3]{.5} = 0.7937002$

$\sqrt[3]{5} = 1.709621$

$\sqrt{3} = 1.7320508$

Temperature Reduction

The Fahrenheit scale is based on 212° as the boiling point of water at normal pressure, 32° as the freezing point. Its zero was formerly supposed to be the lowest temperature attainable artificially.

The Centigrade (Celsius) scale assumes the freezing point of water as being 0°, the boiling point under normal pressure as 100°.

The Reaumur scale assumes the freezing point of water as 0^c, the boiling point of water as 80°.

$$\tfrac{8}{10}\,\text{C.}^\circ = \text{R.}^\circ\ ;\ \tfrac{10}{8}\,\text{R.}^\circ = \text{C.}^\circ$$

$$\tfrac{5}{9}(\text{F.}^\circ - 32) = \text{C.}^\circ\ ;\ \tfrac{9}{5}\,\text{C.}^\circ + 32 = \text{F.}^\circ$$

$$\tfrac{4}{9}(\text{F.}^\circ - 32) = \text{R.}^\circ\ ;\ \tfrac{9}{4}\,\text{R.}^\circ + 32 = \text{F.}^\circ$$

Units of Heat

The British Thermal Unit (B.T.U.) is the quantity of heat equired to raise the temperature of 1 lb. of water 1°F., at or ear its maximum density (39.1°F.).

The calorie (cal.) is the quantity of heat necessary to raise the temperature of 1 gram of water from 10°C. to 11°C. (sometimes also defined as "from 4°C. to 5°C.," less commonly still, from "0°C. to 1°C."

The kilogram-calorie (Cal.) is 1000 times the above.

The pound-calorie is the quantity of heat necessary to raise the temperature of 1 lb. of water 1°C. (usually from 4°C. to 5°C.).

1.0 Cal. = 3.968 B.T.U. = 2.2046 lb.-cal.
1.0 B.T.U. = 0.252 Cal. = 778 ft.-lb.
1 lb.-Cal. = 9/5 B.T.U. = 0.4536 Cal.

Latent heat of a substance is the number of calories required to be absorbed to change 1 gram of the substance from a solid to a liquid or a liquid to a gas, without change of temperature. An equal quantity is given out when the reverse change takes place.

Specific heat of a substance is the ratio of the quantities of heat necessary to raise the temperature of equal masses of the substance and of water from the same to the same temperatures.

The equivalent points on the different scales are

0.0° C = 0.0° R.
− 40.0° C = − 40.0° F.
− 25.6° R = − 25.6° F.

Scale of Temperatures by Color of Iron[1]

Dark red—hardly visible	970°F.	Orange	2000°F.
Dull red	1300°F.	Yellow	2150°F.
Cherry—dark	1450°F.	White heat	2350°F.
Cherry—red	1650°F.	White welding	2600°F.
Cherry—light	1800°F.	White—dazzling	2800°F.

Standard Thermometric Points[2]

Ice melts	0.0°C.	Zinc solidifies	419.4°C.
Water boils	100.0°C.	Sulphur boils	444.7°C.
Aniline boils	184.1°C.	Antimony solidifies	630.7°C.
Naphthalene boils	218.0°C.	Sodium chloride solidifies	801.0°C.
Tin solidifies	231.9°C.	Silver solidifies	960.5°C.
Benzophenone boils	306.0°C.	Copper solidifies	1083.0°C.
Lead solidifies	327.4°C.		

Weights and Measures

Linear Measure—English

12 in. = 1 ft.
3 ft. = 1 yd.
5½ yd. or 16½ ft. = 1 rod or perch.
320 rods, 1760 yd., 5280 ft. = 1 mile.

Also a number of miscellaneous units, some of which are obsolete, or obsolescent, others are used by certain trades only.

[1] For tables of melting points, see pp. 138, 210, 240 and 434. For Seger-cone data see p. 431.
[2] According to the National Physical Laboratory.

A point	= 1/72 in.
A line	= 1/12 in.
A barleycorn	= 1/3 in.
A palm	= 3 in.
A hand	= 4 in.
A span	= 9 in.
A cubit	= 18 in.
A military pace	= 30 in.
A link	= 1/100 chain
A knot (nautical mile)	= 6086 ft.
A fathom	= 6 ft. (United States)
A fathom	= 6.08 ft. (British)
1 ell (English)	= 45 in.
1 ell (Dutch)	= 1.094 yd.
1 bolt	= 40 yd.
A chain	= 4 rods (66 ft.) = 20.117 meters
A furlong	= 1/8 mile
A league	= 3 knots
A cable length	= 120 fathoms (United States)
A cable length	= 608 ft. (British)
An International Geographical mile	= 1/15° at equator = 24,350.3 ft.
A British nautical mile	= 6,080.4 ft.

Linear Measure—French[1]

10 millimeters	= 1 centimeter
10 centimeters	= 1 decimeter
10 decimeters	= 1 meter
10 meters	= 1 dekameter
10 dekameters	= 1 hektometer
10 hektometers	= 1 kilometer
10 kilometers	= 1 myriameter.

A micron is 1/1000 mm.; a millimicron = 1/1000 micron; 1 ångström unit = 1/10 millimicron

Conversion Table, Linear Measure

1 in. = 2.53998 cm.	1 cm. = 0.3937043 in.		
1 ft. = 0.30479 m.	1 m. = 39.36996 in.	= 3.28083 ft.	
1 yd. = 0.914399 m.	1 m. = 1.09362 yd.		
1 mi. = 1.60934 km.	1 km. = 0.62137 mi.	= 3280.83 ft.	

The old French measures and their equivalents are:

1 toise	= 1.9490366 m.
1 pied	= 0.3248394 m.
1 pouce	= 2.706995 cm.
1 ligne	= 0.225583 cm.

1 toise = 6 pieds = 72 pouces = 864 lignes

[1] The decimeter, dekameter, hektometer and myriameter are seldom used as compared with the other measures. When the metric system was devised the meter was supposed to be one ten-millionth part of the quadrant of the earth's surface. However, owing to inaccuracies of measurement, this is only approximately true, and the meter must be defined as the length of a standard bar of platinum kept in Paris, when measured at a temperature of zero degrees centigrade.

Square Measure—English

144 sq. in.	= 1 sq. ft.
9 sq. ft.	= 1 sq. yd.
30.25 sq. yd. 272.25 sq. ft.	= 1 sq. rod
160 sq. rd. 10 sq. ch. 4 roods 43,560 sq. ft.	= 1 acre
640 acres	= 1 sq. mi.
A square of flooring or roofing	= 100 sq. ft.
A section of land	= 1 mi. sq.
A township	= 36 sq. mi.
A board foot	= 1 ft. square × 1 in. thick

Square Measure—French

100 sq. mm.	= 1 sq. cm.
100 sq. cm.	= 1 sq. dm.
100 sq. dm.	= 1 sq. m. (centar)
100 sq. m.	= 1 sq. dekameter or ar
100 sq. dekameters	= 1 sq. hektometer (hektar)
100 sq. hektometers	= 1 sq. kilometer

Conversion Table, Square Measure

1 centar (1 sq. m.) = 1550 sq. in. = 10.764 sq. ft.
1 ar = 119.6 sq. yd.
1 hectar = 2.47104 acres. 1 acre = 0.40469 hektar

1 sq. cm.	= 1.5500 sq. in.	1 sq. in.	= 6.4516 sq. cm.
1 sq. meter	= 10.76390 sq. ft.	1 sq. ft.	= 0.092903 sq. m.
1 sq. km.	= 0.3861 sq. mi.	1 sq. mi.	= 2.58999 sq. km.

Cubic Measure—English[1]

1728 cu. in	= 1 cu. ft.
27 cu. ft.	= 1 cu. yd.
128 cu. ft	= 1 cord

50 cu. ft. of square timber = 1 load
40 cu. ft. of unhewn timber = 1 load
A board foot = 1 ft. square × 1 in. thick

Weight—English

Avoirdupois

16 drams (dr.)	= 1 ounce (oz.)
16 oz.	= 1 pound (lb.)
100 lb.	= 1 hundred-weight (cwt.)
20 cwt.	= 1 ton

Troy

24 grains	= 1 pennyweight (dwt.)
20 dwt.	= 1 oz. Tr.
12 oz. Tr.	= 1 lb. Tr.

[1] For French cubic equivalents see under "Measures of Capacity."

Also in England, and the coal and iron trade in some of the colonies and the United States

112 lb. = 1 long cwt.
1 stone = 14 lb. 2240 lb. = 1 long ton

The Avoirdupois pound	= 7000 grains	= 14.5833 oz. Tr.
The Troy pound	= 5760 grains	= 13.1657 oz. Avoir.
The Avoirdupois ounce	= 437.5 grains	= 0.9115 oz. Tr.
1 ton	= 29,166.66 oz. Tr.	
1 ton	= 0.89287 long ton	
1 long ton	= 1.12 short tons	

(Troy weight is used in weighing gold, silver, platinum, etc. In weighing precious stones the metric carat = 200 mg., is now used.)

1 barrel of flour	= 8 sacks	= 196 lb.
1 barrel of pork	= 200 lb.	
1 barrel of cement	= 4 sacks	= 376 lb.

Weights—French

10 milligrams = 1 centigram	10 centigrams = 1 decigram
10 decigrams = 1 gram	10 grams = 1 dekagram
10 dekagrams = 1 hectogram	10 hectograms = 1 kilogram[1]

100 kilograms = 1 metric quintal
1000 kilograms = 1 metric ton (tonne) or millier

Conversion Table, Weight

1 oz. avoir.	= 28.34954 grams
1 lb. avoir.	= 453.59 grams
1 ton	= 907.18 kg.
1 gram	= 0.035274 oz. avoir. = 0.00220 lb.
1 kg.	= 35.27392 oz. avoir. = 2.2046223 lb.
1 metric ton	= 1.102311 tons = 0.9842 long tons
1 grain	= 64.799 mg.
1 dwt.	= 1.55518 g.
1 oz. Troy	= 31.1035 g.
1 lb. Troy	= 0.37324 kg.
1 gram	= 15.4324 gr. = 0.64301 dwt.
1 mg.	= 0.64301 dwt. = 0.03215 oz. Tr.
1 mg.	= 32.15076 oz. Tr. = 2.67923 lb. Tr.

The *libra* used in Spain, Portugal and Spanish America differs slightly from the U. S. pound, ranging from 1.012 in Portugal and Brazil to 1.016 in Cuba and Porto Rico.

The Assay Ton.—A weight used by assayer such that 1 ton (2000 lb.) : 1 oz. Tr. : : 1 A.T. : 1 mg.; *i.e.*, if the assayer weighs

[1] When the metric system was devised, it was intended that 1 gram should equal the mass of 1 cubic centimeter of water at its greatest density (4°C.) This relation does not exactly hold, and it is necessary to define the gram as the one-thousandth part of a standard mass of platinum kept in Paris. At 4°C. the mass of 1 cc. of water differs so slightly from unity that for nearly all calculations no correction is necessary. According to deLépinay, Benoit and Buisson, 1 kg. of water at 4°C. and 760 mm. pressure = 1000.028 c.c.

out assay tons, each milligram of metal recovered represents 1 Troy oz.

1 A.T. = 29.16667 grams

On the English system, ton of 2240 lb.

1 A.T. = 32.66667 grams

Apothecaries Weight

20 grains	=	1 scruple (℈)
3 ℈	=	1 dram (ʒ)
8 ʒ	=	1 ounce (℥)
12 ℥	=	1 lb. Tr.

Apothecaries Measure

60 minims (♏)	=	1 dram
8 drams	=	1 fluid ounce
16 fl. oz.	=	1 pt.

The apothecaries grain is equal to the Troy grain; the scruple to 5/6 of the pennyweight.

1 gr. = 64.799 mg.	1 ℈ = 32.340 mg.
1 ʒ = 10.780 mg.	1 fl. oz. = 29.5737 milliliters

1 milliliter (1 c.c.) = 0.3381 fl. oz.

Measures of Capacity—English

Dry	Liquid
2 pt. = 1 qt.	4 gills = 1 pt.
8 qt. = 1 peck	2 pt. = 1 qt.
4 pk. = 1 bushel	4 qt. = 1 gal.

31½	gal.	=	1 barrel (bbl.) U. S.
2	bbl.	=	1 hogshead (hhd.)
2	hhd.	=	1 pipe
42	gal.	=	1 bbl. (Standard Oil Co.), formerly a tierce
84	gal. (2 tierces)	=	1 puncheon

A liquid gallon (U. S.)	contains	231.0 cu. in.
An Imperial gallon	contains	277.408 cu. in.[1]
A bushel (U. S.)	contains	2150.42 cu. in.
An Imperial bushel	contains	2218.192 cu. in.[2]
A quarter	contains	8 Imperial bu.

NOTE.—It can be seen that the dry quart contains 67⅕ cu. in., while the liquid quart contains only 57¾ cu. in. There is therefore no royal road to reducing dry measures to wet equivalents.

1 Imperial gal.	=	1.20094 U. S. gal.
1 U. S. gal.	=	0.83268 Imp. gal.
1 Imp. bu.	=	1.03151 U. S. bu.
1 U. S. bu.	=	0.96945 Imp. bu.
1 gal. (ale or beer)	=	1.2208 U. S. gal.

[1] Sometimes given 277.274.
[2] Sometimes given 2219.28.

Grains per U. S. gal.	× 17.138	=	parts per million
Grains per Imp. gal.	× 14.285	=	parts per million
Parts per million	× 0.583	=	grains per U. S. gal.
Parts per million	× 0.700	=	grains per Imp. gal.

Measures of Capacity—French

1000 cu. mm.	=	1 c.c.
1000 c.c.	=	1 cu. dm. (liter)
1000 cu. dm.	=	1 cu. m.

In measuring wood, the cubic meter is called a ster.

10 milliliters	=	1 centiliter
10 centiliters	=	1 deciliter
10 deciliters	=	1 liter
10 liters	=	1 dekaliter
10 dekaliters	=	1 hectoliter
10 hectoliters	=	1 kiloliter

Conversion Tables, Cubic Measure

1 cu. in.	=	16.38720 c.c.
1 c.c.	=	0.06102376 cu. in. = 0.0000353 cu. ft.
1 cu. ft.	=	0.028317 cu. m.
1 cu. m.	=	35.31445 cu. ft. = 1.30794 cu. yd.
1 cu. yd.	=	0.764553 cu. m.

Liquid Equivalents

1 fl. oz.	=	29.57370 milliters
1 milliliter	=	0.3381 fl. oz. = 0.061027 cu. in.
1 gill	=	1.1829 deciliters
1 deciliter	=	0.8454 gills
1 quart	=	0.94636 liters
1 liter	=	1.0567 quarts.
1 U. S. gal.	=	3.78543 dekaliter
1 dekaliter	=	2.6417 gal.

Dry Equivalents

1 pt.	=	5.5061 centiliters
1 centiliter	=	0.18162 pt.
1 qt.	=	1.10122 liters
1 liter	=	0.90808 quarts
1 pk.	=	0.08810 hectoliter
1 hectoliter	=	2.8377 bu.
1 bu. (U. S.)	=	0.35239 hectoliter
1 kiloliter	=	1.3079 cu. yd.

Circular and Angular Measure

60 sec. (″)	=	1 minute (′)
60 min. (′)	=	1 degree (°)
360 deg. (°)	=	1 circumference

In the higher mathematics another unit is used:

2π radians = 1 circumference

$\therefore$ 1 radian = 57.2957795° = 57° 17′ 44.806″

Time

60 sec. = 1 min.; 60 min. = 1 hr.; 24 hr. = 1 day
365.242218 solar days = 1 year
29 days 12 hr. 44 min. = 1 lunar month

A seconds pendulum = 39.138 in. = 0.9958 meters in the latitude of New York at sea level.

The period of a pendulum is $\pi\sqrt{\frac{l}{g}}$, where l is length, and g the acceleration due to gravity.

Miscellaneous

20 units	= 1 score	24 sheets	= 1 quire
12 units	= 1 dozen	20 quires	= 1 ream
12 dozen	= 1 gross	2 reams	= 1 bundle
12 gross	= 1 great gross	5 bundles	= 1 bale

1 atmosphere = 14.7 lb. per sq. in. = 29.922 in. of mercury = 33.9 ft. of water

C.G.S. Units

The unit of force is the dyne. It is that force which applied to a mass of one gram will give it an acceleration of one centimeter in one second.

The unit of work is the erg. This is the work done by one erg acting through a distance of one centimeter. The joule = 10^7 ergs.

A calorie is the heat necessary to raise the temperature of 1 gram of water from 0°C. to 1°C.

A great calorie (Calorie) is the heat necessary to raise the temperature of 1 kg. of water from 0°C. to 1°C.

Unit	Erg	Joule	Kilogram-meter (g. = 981)	Calorie	Small calorie
Erg	1	10^{-7}	1.019×10^{-8}	2.39011×10^{-11}	2.39011×10^{-8}
Joule	10^7	1	1.019	2.39011×10^{-4}	2.39011×10^{-1}
Kilogram-meter (g. = 981)	981.0×10^5	9.81	1	2.3446×10^{-3}	2.3446
Calorie	418.4×10^8	4184	426.5	1	1000

The unit magnetic mass or pole is such that placed at a distance of one centimeter from an identical mass, it exercises a repulsion equal to 1 dyne.

The permeability is the ratio of flux density to magnetic intensity.

The unit of electric current in the C.G.S. system is a current that exerts a force of one dyne on a unit magnetic pole placed at the center of an arc of the circuit, 1 cm. long, and 1 cm. radius. The practical unit is the ampere (see below), which is one-tenth the C.G.S. unit.

The C.G.S. unit of quantity is the quantity which in one second is conveyed by a C.G.S. unit of current. The practical unit is the coulomb, the quantity of current passing per second, in a current carrying one ampere. It is one-tenth the C.G.S. unit.

The C.G.S. unit of potential difference or electromotive force is the potential difference which exists between two points of a conductor conveying a unit current when one erg of work is done per second. The practical unit is the volt (see below) $= 10^8 \times$ the C.G.S. unit.

The C.G.S. unit of resistance is the resistance possessed by a conductor through which a unit e.m.f. causes a unit current to flow. The practical unit is the ohm (see below) $= 10^9 \times$ the C.G.S. unit.

The C.G.S. unit of capacity of a condenser is that capacity which gives a unit potential difference between the coatings when either coating has a unit quantity of electricity. The farad is the practical unit and equals 10^{-9} times the C.G.S. unit.

A **Gauss** is the unit of field strength, the intensity of field which acts on a unit pole with a force of one dyne. A unit magnetic pole has 4π lines of force proceeding from it. It is equal to gilberts per centimeter length. Gausses = maxwells $\div$ area.

A **Maxwell** is the unit of magnetic flux, the amount of magnetism passing through every square centimeter of a field of unit density. The weber is 1,000,000 maxwells. If a conductor cuts a magnetic field so that one volt is induced, 100,000,000 maxwells are cut per second.

A **Gilbert** is the unit of magneto-motive force, the amount produced by $\frac{10}{4\pi} = 0.7958$ ampere turns. The m.m.f. of a coil is 1.2566 times the ampere turns. ϕ = flux in maxwells.

Reluctance is that quantity in a magnetic circuit which limits the flux under a given m.m.f. It corresponds to the resistance in the electric circuit.

The Oersted is the unit of magnetic reluctance, it is the reluctance of a cubic centimeter of an air-pump vacuum.

Inductance is the property of a circuit which opposes any change in current flowing by inducing a counter-electromotive force in the circuit at the time the current is changing. The practical unit is the henry (see below) $= 10^9 \times$ the C.G.S. unit.

PRACTICAL ELECTRICAL UNITS

Ohm—unit of resistance. The International Ohm[1] is the resistance offered to an unvarying electric current by a column

[1] The true ohm ($= 10^9$ electromagnetic C.G.S. units) is apparently the resistance of 106.29 cm. of mercury 1 sq. cm. in section. The 1884 legal ohm = 0.9972 int'l. ohms. The B.A. ohm = 0.9866 int'l. ohm.

A joule is almost equal to the energy expended in one second by an international ampere in an international ohm.

of mercury at 0°C., 14.4521 grams in mass, of a constant cross section, and of a length of 106.3 cm.

Coulomb—unit of quantity. Equal to one ampere passing for one second.

Ampere—unit of current. The International Ampere is the unvarying electric current which, when passed through a solution of nitrate of silvėr in water, under certain specifications, deposits silver at the rate of 0.00111800 grams per second.

International Volt—unit of pressure. It is that electrical pressure which will steadily produce a one-ampere current through a one-ampere resistance. For practical use it is $\frac{1000}{1434}$ of the e.m.f. of the Clark cell at 15°C.

International Watt—unit of energy. It is the energy expended per second by an unvarying electric current of one International Ampere under an electric pressure of an International Volt.

International Farad—unit of capacity. It is the capacity of a conductor which is charged to a potential of one volt by one coulomb of electricity.

International Henry—unit of inductance. It is the inductance in the circuit when the e.m.f. induced in the circuit is one international volt, while the inducing current varies at the rate of one international ampere per second.

Ohm's Law.—Current in amperes =

$$\frac{\text{Pressure in volts}}{\text{Resistance in ohms}} \text{ or } I = \frac{E}{R}$$

Power in watts equals energy of the current multiplied by the voltage.

Direct current—P (watts = E (volts) $\times$ I (amperes)

$$= \frac{E^2}{R} = IR^2$$

Alternating current—

single-phase, $P = EI \times$ Power factor

two-phase, $P = \sqrt{2}EI \times$ Power factor (line values; two wire)

three-phase, $P = \sqrt{3}EI \times$ Power factor (line values; three wire)

Units of Force

1 poundal = 13,825 dynes
1 gram's weight = 980 dynes
1 pound's weight = 444,518 dynes

Work and Energy

1 foot-pound = 1.383×10^7 ergs = 1.383 joules = 0.1383 kilogram-meters
1 watt = 1 joule per second
1 kilogram-meter = 7.283 foot-pounds

Weight, Force or Pressure, Combined with Areas

1 atmosphere = 760 mm. of mercury = 29.9212 in. of mercury
= 10.3329 m. of water = 33.9006 ft. of water
= 1.03329 kg. per sq. cm. = 14.6969 lb. per sq. in.

1 barie = 1 dyne per sq. cm. = 0.00208870 lb. per sq. ft.

1 foot-pound = 13.8255 kilogram centimeters = 3.306×10^{-4} cal.

1 kg. per sq. m. = 14.2234 lb. per sq. in.

1 lb. carbon oxidized to CO_2 = 14,544 heat units.

Table of Equivalent Values for Power Expressed in Various English and Metric Units

	Watt	Kw.	English h.p.	Conti-nental h.p.	Kg.-m. per sec.	Ft.-lb. per sec.	Kg.-cal. per sec.	B.t.u. per sec.
1 watt is equal to...	1.000	0.001000	0.00134	0.00136	0.102	0.737	0.000238	0.000947
1 kw. is equal to.........	1000.0	1.000	1.34	1.36	102.0	737.0	0.238	0.947
1 English (and American) h.p...	746.0	0.746	1.000	1.015	76.0	550.0	0.178	0.707
1 Continental h.p.....	735.0	0.735	0.985	1.000	75.0	541.0	0.175	0.696
1 kg.-m. per sec........	9.81	0.00981	0.0131	0.0133	1.000	7.233	0.00234	0.00930
1 ft.-lb. per sec........	1.356	0.00136	0.00182	0.00185	0.138	1.000	0.000324	0.00129
1 kg.-cal. per sec........	4200.0	4.20	5.61	5.70	427.0	3090.0	1.000	3.968
1 B.t.u. per sec........	1055.0	1.055	0.415	0.422	107.6	778.0	0.252	1.000

Light—velocity of, 299,583 km. per sec. = 186,319 mi. per sec.
Wave length, red light—*B* line—0.000068702 cm.
Wave length, violet light—*K* line—0.000039338 cm.

Some Foreign Weights and Measures and the U. S. Equivalents[1]

1 almude (Portugal) = 4.422 gal.
1 arobe (Paraguay) = 25 lb.
1 arroba, dry (Argentine) = 25.3171 lb.
1 arroba, liquid (Cuba, Spain, Venezuela) = 4.263 gal.
1 arshine (Russia) = 28 in.
1 sq. arshine (Russia) = 5.44 sq. ft.
1 baril (Argentine, Mexico) = 20.079 gal.
1 braca (Brazil) = 2.407 yards
1 bu (Japan) = 0.119305 in.
1 candy (India) = 529 lb.

[1] "Foreign Weights, Measures and Moneys." By John J. Macfarlane.

1 catty (China)	= 1.333 lb.
1 catty (Japan)	= 1.323 lb.
1 catty (Java)	= 1.356 lb.
1 catty (P. I.)	= 1.39 lb.
1 catty (Str. Sett.)	= 1.333 lb.
1 catty (Sumatra)	= 2.118 lb.
1 centaro (Central America)	= 4.2631 gal.
1 chih (China)	= 1.049867 ft.
1 cho (Japan)	= 357.916 ft.
1 cuadra (Argentine)	= 4.2 acres
1 dessiatine (Russia)	= 2.6997 acres
1 doli (Russia)	= 0.685 grains
1 fanega (Argentine)	= 3.89 bu.
1 fen (China)	= 0.12598 in.
1 fen (sq.) (China)	= 0.015181 acres
1 funt (Russia)	= 0.9028 lb. = 409 grams
1 go (Japan)	= 1.270506 gill liquid = 0.0198517 peck dry
1 hao (China)	= 0.001260 in.
1 sq. hao (China)	= 0.00015181 acres
1 jo (Japan)	= 3.31404 yd.
1 ken (Japan)	= 1.983427 yd.
1 kin (Japan)	= 1.32277 lb. Avoir.
1 koku (Japan)	= 39.7033 gal. liquid = 4.96291 bu. dry
1 kwan (Japan)	= 8.26733 lb. Avoir.
1 legua (Brazil)	= 4.102 miles
1 li (China)	= 0.012598 in.
1 liang (China)	= 1.31561 oz. Avoir.
1 lyi (China)	= 0.0015181 acres
1 manzana (Costa Rica)	= 1.625 acres
1 marc (Bolivia)	= 0.507 lb.
1 maund (Bengal)	= 82.2855 lb.
1 maund (Bombay)	= 28 lb.
1 maund (Madras)	= 25 lb.
1 meou (China)	= 0.15181 acres
1 milla (Nicaragua, Honduras)	= 1.1493 miles
1 momme (Japan)	= 2.4123045 dwt.
1 pie (Argentine)	= 0.9478 ft.
1 pikul (Borneo)	= 135.6354 lb.
1 pikul (China)	= 133⅓ lb.
1 pikul (Japan)	= 132.277 lb.
1 pikul (Java)	= 135.6 lb.
1 pikul (P. I.)	= 139.485 lb.
1 pikul (Str. Sett.)	= 133⅓ lb.
1 pood (Russia)	= 36.1128 lb.
1 pulgada (Argentine)	= 0.947 in.
1 quintal (Argentina)	= 101.28 lb.
1 quintal (Bolivia, Chile, Colombia, Dominican Repub., Spain)	= 101.4 lb.
1 quintal (Brazil)	= 129.526 lb.

1 quintal (Costa Rica)	= 101.465 lb.
1 quintal (Syria, Turkey)	= 125 lb.
1 ri (Japan)	= 2.440338 mi.
1 ri (marine) (Japan)	= 1.1506873 mi.
1 sagene (Russia)	= 7 ft.
1 sashen (Russia)	= 7 lb.
1 shaku (Japan)	= 11.9305424 in.
1 sheng (China)	= 2.7354 liq. gal.
1 sho (Japan)	= 1.5881325 qt. liquid = 0.1985166 pecks dry
1 sun (Japan)	= 1.1930542 in.
1 tan (Japan)	= 0.24507 acre
1 tch'e (China)	= 12.598 in.
1 tchetvert (Russia)	= 117,600 sq. ft.
1 to (Japan)	= 3.9703313 gal. liquid
1 ts'onen (China)	= 1.2598 in.
1 tsubo (Japan)	= 3.953829 sq. yd.
1 vara (Argentine)	= 34.1208 in.
1 verchok (Russia)	= 1.75 in.
1 verst (Russia)	= 3,500 ft.
1 zolotnik (Russia)	= 658 grains

UNITED STATES AND FOREIGN MONEY

(The following figures are based on the gold standard only and do not include exchange.)

Argentina (gold)	1 peso	= $0.9648	= 100 centavos
Argentina (paper)	1 peso	= 0.4246	= 100 centavos
Austria	1 krone	= 0.203	= 100 heller
Bolivia	1 boliviano	= 0.3893	= 100 centavos
Brazil	1 milreis	= 0.5463	= 1000 reis
Ceylon	1 rupee	= 0.32443	= 100 cents
Chile	1 peso	= 0.365	= 100 centavos
China	1 Haikwan tael	= 1⅓ oz. avoir. of silver	= 10 mace
Columbian Rep'b.	1 peso	= 1.00	= 100 centavos
Costa Rica	1 colon	= 0.4654	= 100 centavos
Denmark	1 krone	= 0.268	= 100 öre
Ecuador	1 sucre	= 0.4867	= 100 centavos
Egypt	1 pound (£E)	= 4.943 = 1000 milliemes	= 100 piastres
France	1 franc	= 0.193	= 100 centimes
Germany	1 mark	= 0.238	= 100 pfennig
Great Britain	1 pound (£)	= 4.8665	= 20 shillings = 240 pence[1]
Greece	1 drachma	= 0.193	= 100 lepta
Guatemala	1 peso	= 0.965	= 100 centavos
Haiti	1 gourde	= 0.965	= 100 centimes
Honduras	1 peso	= 0.3979	= 100 centavos
Hongkong	1 dollar	= 0.463	= 100 cents = 1000 cash
Hungary	1 krone	= 0.2026	= 100 filler
India	1 rupee (Rs.)	= 0.32443	= 16 annas = 192 pies[2]
Italy	1 lira	= 0.193	= 100 centesimos
Japan	1 yen	= 0.498	= 100 sen = 1000 rin
Mexico	1 peso	= 0.498	= 100 centavos
Netherlands	1 guilder	= 0.0402	= 100 cents
Nicaragua	1 peso	= 0.965	= 100 centavos
Norway	1 krone	= 0.268	= 100 öre
Panama	1 balboa	= 1.00 = 200 centisimos	= 2 silver pesos
Peru	1 libra (£P)	= 4.8665	= 10 dinero = 100 centavos

[1] 5 shillings = 1 crown; 21 sh. = 1 guinea; 4 farthings = 1 penny (d.).
[2] A lakh = 100,000 rupees; a crore = 10,000,000 rupees.

Philippine Is.	1 peso	= 0.50	= 100 centavos
Portugal	1 milreis	= 1.08	= 1000 reis
Roumania	1 leu	= 0.193	= 100 bani
Russia	1 ruble	= 0.515	= 100 kopecks
Salvador	1 peso	= 0.3978	= 100 centavos
Spain	1 peseta	= 0.193	= 100 centisimos
Straits Settlements	1 dollar	= 0.5677	= 100 cents
Sweden	1 krona	= 0.268	= 100 öre
Turkey	1 pound (£T)	= 4.40	= 100 piasters = 4000 paras
Uruguay	1 peso	= 1.0342	= 100 centavos
Venezuela	1 bolivar	= 0.1930	= 100 centimos

COINAGE STANDARDS[1]

Country	Gold coin	Silver coin	Country	Gold coin	Silver coin
Abyssinia	.....	835	Honduras	.....	900
Argentine	900.0	900	Honduras (British)	.....	925
Austria-Hungary	900.0	900,835	Hongkong	.....	800
Belgium	900.0	900,835	India	916.6	916.6
Bolivia	.....	900	Italy	900.0	900,835
Brazil	916.6	916.6	Japan	900.0	800
Bulgaria	900.0	900,835	Mauritius	.....	800
Canada	.....	925	Mexico	.....	902.7,800
Ceylon	.....	800	Morocco	.....	900,835
Chile	916.6	500	Newfoundland	916.6	925
China	.....	900,866,820	Nicaragua	.....	800
Colombia	900.0	900,835	Norway	900.0	800,600,400
Congo	900.0	900,835	Panama	900.0	900
Corea	900.0	800	Paraguay	.....	900
Costa Rica	900.0	900	Persia	900.0	900
Crete	900.0	900,835	Peru	916.6	900
Curaçao	.....	640	Portugal	916.6	916.6
Cyprus	.....	925	Roumania	900.0	900,835
Denmark	900.0	800,600,400	Russia	900.0	900,500
Dominica	.....	900,835	Salvador	900.0	900,835
Dutch East Indies	.....	720	Servia	900.0	900,835
Ecuador	900.0	900	Siam	.....	900
Egypt	875.0	833.3	South Africa	916.6	925
Finland	900.0	868,750	Spain	900.0	900,835
France	900.0	900,835	Sweden	900.0	800,600,400
Germany	900.0	900	Straits Settlements	.....	900,800
Great Britain	916.0	925	Switzerland	900.0	900.835
Greece	900.0	900,835	Turkey	916.6	830
Guatemala	900.0	900,835	United States	900.0	900
Hayti	900.0	900,835	Uruguay	.....	900
Holland	900.0	945,640	Venezuela	900.0	900,835

ALGEBRA

Powers and Roots

According to the binomial theorem

$$(a+b)^K = a^K + Ka^{K-1}b + \frac{K(K-1)}{1 \cdot 2}a^{K-2}b^2 + \frac{K(k-1)(k-2)}{1 \cdot 2 \cdot 3}a^{K-3}b^3 + \dots \frac{K\,(K-1)\;\dots\;{}^3a^2b^{K-2}}{1 \cdot 2 \cdot 3\;\dots\;(K-2)} + \frac{K(K-1)\;\dots\;2}{1 \cdot 2 \cdot 3\;\dots\;(K-1)}ab^{k-1} + b^k$$

[1] T. K. Rose, "Precious Metals."

This formula will serve for the solution of any power whatever, and will, in general, serve to indicate the process of the extraction of roots. However, for all practical work on roots and powers, use the table of logarithms on p. 42.

$$\log a^k = k \log a$$

$$\log \sqrt[k]{a} = \frac{\log a}{k}.$$

Permutation, Choice and Chance

The number of different arrangements (or permutations) of n different things taken altogether is factorial n.

($n!$ or $\underline{|n} = n(n-1)(n-2) \ldots 3 \times 2 \times 1$)

The number of different selections (or combinations) of n different things taken r at a time is:

$$\frac{n(n-1)(n-2) \ldots (n-r+1)}{\underline{|r}}$$

The number of selections of n things taken r at a time is the same as the number of selections of n things taken n − r at a time.

The number of selection of n things taken r at a time is greatest when: If n is an odd number,

$$r = \frac{n-1}{2}$$

if n is an even number

$$r = \frac{n}{2}$$

The chance of an event happening is expressed by the fraction of which the numerator is the number of favorable ways, and the denominator the whole number of ways, favorable and unfavorable.

If there are several events of which one, and only one can happen, the chance that one will happen is the sum of the respective chances of happening.

Progression

The chief "progressions" are arithmetical, geometrical, and harmonic. They are series of numbers in which a common law connects the successive terms.

Arithmetical progression in a series of numbers consists in a constant difference between the successive terms, as

$$1, 3, 5, 7, 9, \ldots$$

Let a = first term; l = last term; d = the common difference; n = the number of terms; s = the sum of the terms.

$$l = a + (n-1)d = \frac{2s}{n} - a = \frac{s}{n} + \frac{(n-1)d}{2} = -\frac{1}{2}d \pm \sqrt{2ds + \left(a - \frac{d}{2}\right)^2}.$$

$$s = \frac{n}{2}\left[2a + (n-1)d\right] = \frac{n}{2}(l + a) = \frac{n}{2}\left[2l - (n-1)d\right] = \frac{l+a}{2}\left(\frac{d+l-a}{d}\right)$$

$$a = l - (n-1)d = \frac{2s}{n} - l = \frac{s}{n} - \frac{(n-1)d}{2} = \frac{1}{2}d \pm \sqrt{\left(l + \frac{d}{2}\right)^2 - 2ds}$$

$$d = \frac{l-a}{n-1} = \frac{2(s-an)}{n(n-1)} = \frac{l^2 - a^2}{2s - l - a} = \frac{2(nl - s)}{n(n-1)}$$

$$n = \frac{l-a}{d} + 1 = \frac{2s}{l+a} = \frac{d - 2a \pm \sqrt{(2a-d)^2 + 8ds}}{2d} = \frac{2l + d \pm \sqrt{(2l+d)^2 - 8ds}}{2d}$$

Geometrical progression in a series of numbers consists in a constant ratio existing between the successive terms, as

4, 8, 16, 32, . . .

Let a = first term; l = last term; m = any (middle) term; s = sum; r = ratio or constant multiplier.

$$l = ar^{n-1} = \frac{a + (r-1)s}{r} = \frac{(r-1)sr^{n-1}}{r^{n-1}}$$

$$m = ar^{m-1}$$

$$s = \frac{a(r^n - 1)}{r - 1} = \frac{rl - a}{r - 1} = \frac{\sqrt[n-1]{l^n} - \sqrt[n-1]{a^n}}{\sqrt[n-1]{l} - \sqrt[n-1]{a}} = \frac{lr^n - l}{r^n - r^{n-1}}$$

$$a = \frac{l}{r^{n-1}} = \frac{(r-1)s}{r^{n-1}} = rl - (r-1)s$$

$$r = \sqrt[n-1]{\frac{l}{a}} = \frac{s-a}{s-l}$$

$$r^n - \frac{s}{a}r + \frac{s-a}{a} = r^n - \frac{s}{s-l}r^{n-1} + \frac{l}{s-l} = 0$$

Harmonic series is one in which the numbers are the reciprocals of those forming an arithmetical progression. Such series are of small practical value, and such questions as arise in them, when solvable, are best answered by inverting the series, and solving as a problem in arithmetical progression. In ancient times a fictitious importance was attached to them owing to the fact that a series of uniform rods of lengths in harmonic progression form a musical scale, hence the name.

INTEREST, ANNUITIES, SINKING FUNDS

Simple Interest

If the principal be represented by	P
the interest on \$1 for one year by	r
the amount of \$1 for one year by	R
the number of years by	n
the amount of P after n years by	A

Then $R = 1 + r$

Simple interest on P for one year $= Pr$

Amount of P for one year $= PR$

Simple interest on P for n years $= Pnr$

Amount P for n years $= P(1 + nr)$

that is $A = P(1 + nr)$

When any three of the quantities A, P, n, r, are given, the fourth may be found from this last equation.

Since P will in n years at r interest amount to A, P may be considered equivalent in value to A at the end of n years; in other words, P is the "present worth" of A.

Compound Interest

When compound interest is reckoned payable annually.

The amount of P dollars in

1 year is $P(1 + r) = PR$

2 years is $PR(1 + r) \doteq PR^2$

n years $= PR^n$

$$\text{or } A = PR^n \text{ or } P = \frac{A}{R^n}$$

When compound interest is reckoned semi-annually.

The amount of P dollars in

½ year is $P\left(1 + \frac{r}{2}\right)$

1 year is $P\left(1 + \frac{r}{2}\right)^2$

n years, $A = P\left(1 + \frac{r}{2}\right)^{2n}$

When the interest is payable quarterly

$$A = P\left(1 + \frac{r}{4}\right)^{4n}$$

When the interest is payable monthly

$$A = P\left(1 + \frac{r}{12}\right)^{12n}$$

And when the interest is payable q times a year

$$A = P\left(1 + \frac{r}{q}\right)^{qn}$$

Sinking Funds

If the sum set apart at the end of each year to be put at compound interest be represented by S, then, the sum at the end of the

first year $= S$

second year $= S + SR$

third year $= S + SR + SR^2$

nth year $= S + SR + SR^2 \; . \; . \; . \; SR^{n-1}$

$$A = S + SR + SR^2 \; . \; . \; . + SR^{n-1}$$

$$\therefore AR = SR + SR^2 \; . \; . \; . + SR^{n-1} + SR^n$$

$$\therefore AR - A = SR^n - S$$

$$A = \frac{S(R^n - 1)}{R - 1} = S\frac{(R^n - 1)}{r}$$

Compound Interest and Discount Tables

Years	Two per cent.				Two and one-half per cent.			
	Am't of $1 in *n* yrs.	Present val. of $1 due in *n* yrs.	Am't of $1 per annum in *n* yrs.	Present val. of $1 annuity for *n* yrs.	Am't of $1 in *n* yrs.	Present val. of $1 due in *n* yrs.	Am't of $1 per annum in *n* yrs.	Present val. of $1 annuity for *n* yrs.
1	$1.020	.9804	1.02	1.000	1.025	.9756	1.03	1.000
2	1.040	.9612	2.06	1.980	1.051	.9518	2.08	1.976
3	1.061	.9423	3.12	2.942	1.077	.9286	3.15	2.927
4	1.082	.9238	4.20	3.884	1.104	.9060	4.26	3.856
5	1.104	.9057	5.31	4.808	1.131	.8839	5.39	4.762
6	1.126	.8880	6.43	5.713	1.160	.8623	6.55	5.646
7	1.149	.8706	7.58	6.601	1.189	.8413	7.74	6.508
8	1.172	.8535	8.75	7.472	1.218	.8207	8.95	7.349
9	1.195	.8368	9.95	8.325	1.249	.8007	10.20	8.170
10	1.219	.8203	11.17	9.162	1.280	.7812	11.48	8.971
11	1.243	.8043	12.41	9.983	1.312	.7621	12.80	9.752
12	1.268	.7885	13.68	10.787	1.345	.7436	14.14	10.514
13	1.294	.7730	14.97	11.575	1.379	.7254	15.52	11.258
14	1.319	.7579	16.29	12.348	1.413	.7077	16.93	11.983
15	1.346	.7430	17.64	13.106	1.448	.6905	18.38	12.691
16	1.373	.7284	19.01	13.849	1.485	.6736	19.86	13.381
17	1.400	.7142	20.41	14.578	1.522	.6572	21.39	14.055
18	1.428	.7002	21.84	15.292	1.560	.6412	22.95	14.712
19	1.457	.6864	23.30	15.992	1.599	.6255	24.54	15.353
20	1.486	.6730	24.78	16.678	1.639	.6103	26.18	15.979
21	1.516	.6598	26.30	17.351	1.680	.5954	27.86	16.589
22	1.546	.6468	27.84	18.011	1.722	.5809	29.58	17.185
23	1.577	.6342	29.42	18.658	1.765	.5667	31.35	17.765
24	1.608	.6217	31.03	19.292	1.809	.5529	33.16	18.332
25	1.641	.6095	32.67	19.914	1.854	.5394	35.01	18.885
26	1.673	.5976	34.34	20.523	1.900	.5262	36.91	19.424
27	1.707	.5859	36.05	21.121	1.948	.5134	38.86	19.951
28	1.741	.5744	37.79	21.707	1.996	.5009	40.86	20.464
29	1.776	.5631	39.57	22.281	2.046	.4887	42.90	20.965
30	1.811	.5521	41.38	22.844	2.098	.4767	45.00	21.454
31	1.848	.5412	43.23	23.396	2.150	.4651	47.15	21.930
32	1.885	.5306	45.11	23.938	2.204	.4538	49.35	22.395
33	1.922	.5202	47.03	24.468	2.259	.4427	51.61	22.849
34	1.961	.5100	48.99	24.989	2.315	.4319	53.93	23.292
35	2.000	.5000	50.99	25.499	2.373	.4214	56.30	23.724
36	2.040	.4902	53.03	25.999	2.433	.4111	58.73	24.145
37	2.081	.4802	55.11	26.489	2.493	.4011	61.23	24.556
38	2.122	.4712	57.24	26.969	2.556	.3913	63.78	24.957
39	2.165	.4619	59.40	27.441	2.620	.3817	66.40	25.349
40	2.208	.4529	61.61	27.903	2.685	.3724	69.09	25.730
41	2.252	.4440	63.86	28.355	2.752	.3633	71.84	26.103
42	2.297	.4353	66.16	28.799	2.821	.3545	74.66	26.466
43	2.343	.4268	68.50	29.235	2.892	.3458	77.55	26.821
44	2.390	.4184	70.89	29.662	2.964	.3374	80.52	27.166
45	2.438	.4102	73.33	30.080	3.038	.3292	83.55	27.504
46	2.487	.4022	75.82	30.490	3.114	.3211	86.67	27.833
47	2.536	.3943	78.35	30.892	3.192	.3133	89.86	28.154
48	2.587	.3865	80.94	31.287	3.271	.3057	93.13	28.467
49	2.639	.3790	83.58	31.673	3.353	.2982	96.48	28.773
50	2.692	.3715	86.27	82.052	3.437	.2909	99.92	29.071

For interest at 4, 5 and 6 per cent., payable semi-annually, use the tables at 2, 2½ and 3 per cent., dividing the year numeral by 2.

The fourth column, "present value of $1 annuity for *n* years," is calculated for an annuity payable at the beginning of the year. The data for an annuity payable at the end of the year by taking the next year's figure and deducting $1 from it.

Compound Interest and Discount Tables

Years	Three per cent.				Three and one-half per cent.			
	Am't of $1 in *n* yrs.	Present val. of $1 due in *n* yrs.	Am't of $1 per annum in *n* yrs.	Present val. of $1 annuity for *n* yrs.	Am't of $1 in *n* yrs.	Present val. of $1 due in *n* yrs.	Am't of $1 per annum in *n* yrs.	Present val. of $1 annuity for *n* yrs.
1	$1.030	.9709	1.03	1.000	$1.035	.9662	1.04	1.000
2	1.061	.9426	2.09	1.971	1.071	.9335	2.11	1.966
3	1.093	.9151	3.18	2.913	1.109	.9019	3.21	2.900
4	1.126	.8885	4.31	3.829	1.148	.8714	4.36	3.802
5	1.159	.8626	5.47	4.717	1.188	.8420	5.55	4.673
6	1.194	.8375	6.66	5.580	1.229	.8135	6.78	5.515
7	1.230	.8131	7.89	6.417	1.272	.7860	8.05	6.329
8	1.267	.7894	9.16	7.230	1.317	.7594	9.37	7.115
9	1.305	.7664	10.46	8.020	1.363	.7337	10.73	7.874
10	1.344	.7441	11.81	8.786	1.411	.7089	12.14	8.608
11	1.384	.7224	13.19	9.530	1.460	.6849	13.60	9.317
12	1.426	.7014	14.62	10.253	1.511	.6618	15.11	10.002
13	1.469	.6810	16.09	10.954	1.564	.6394	16.68	10.663
14	1.513	.6611	17.60	11.635	1.619	.6178	18.30	11.303
15	1.558	.6419	19.16	12.296	1.675	.5969	19.97	11.921
16	1.605	.6232	20.76	12.938	1.734	.5767	21.71	12.517
17	1.653	.6050	22.41	13.561	1.795	.5572	23.50	13.094
18	1.702	.5874	24.12	14.166	1.857	.5384	25.36	13.651
19	1.754	.5703	25.87	14.754	1.923	.5202	27.28	14.190
20	1.806	.5537	27.68	15.324	1.990	.5026	29.27	14.710
21	1.860	.5375	29.54	15.877	2.059	.4856	31.33	15.212
22	1.916	.5219	31.45	16.415	2.132	.4692	33.46	15.698
23	1.974	.5067	33.43	16.937	2.206	.4533	35.67	16.167
24	2.033	.4919	35.46	17.444	2.283	.4380	37.95	16.620
25	2.094	.4776	37.55	17.936	2.363	.4231	40.31	17.058
26	2.157	.4637	39.71	18.413	2.446	.4088	42.76	17.482
27	2.221	.4502	41.93	18.877	2.532	.3950	45.29	17.890
28	2.288	.4371	44.22	19.327	2.620	.3817	47.91	18.285
29	2.357	.4243	46.58	19.764	2.712	.3687	50.62	18.667
30	2.427	.4120	49.00	20.188	2.807	.3563	53.43	19.036
31	2.500	.4000	51.50	20.600	2.905	.3442	56.33	19.392
32	2.575	.3883	54.08	21.000	3.007	.3326	59.34	19.736
33	2.652	.3770	56.73	21.389	3.112	.3213	62.45	20.069
34	2.732	.3660	59.46	21.766	3.221	.3105	65.67	20.390
35	2.814	.3554	62.28	22.132	3.334	.3000	69.01	20.701
36	2.898	.3450	65.17	22.487	3.450	.2898	72.46	21.001
37	2.985	.3350	68.16	22.832	3.571	.2800	76.03	21.290
38	3.075	.3252	71.23	23.167	3.696	.2706	79.72	21.571
39	3.167	.3158	74.40	23.492	3.825	.2614	83.55	21.841
40	3.262	.3066	77.66	23.808	3.959	.2526	87.51	22.103
41	3.360	.2976	81.02	24.115	4.098	.2440	91.61	22.355
42	3.461	.2890	84.48	24.412	4.241	.2358	95.85	22.599
43	3.565	.2805	88.05	24.701	4.390	.2278	100.24	22.835
44	3.671	.2724	91.72	24.982	4.543	.2201	104.78	23.063
45	3.782	.2644	95.50	25.254	4.702	.2127	109.48	23.283
46	3.895	.2567	99.40	25.519	4.867	.2055	114.35	23.495
47	4.012	.2493	103.41	25.775	5.037	.1985	119.39	23.701
48	4.132	.2420	107.54	26.025	5.214	.1918	124.60	23.899
49	4.256	.2350	111.80	26.267	5.396	.1853	130.00	24.091
50	4.384	.2281	116.18	26.502	5.585	.1791	135.58	24.277

Compound Interest and Discount Tables

Years	Four per cent.				Five per cent.			
	Am't of $1 in *n* yrs.	Present val. of $1 due in *n* yrs.	Am't of $1 per annum in *n* yrs.	Present val. of $1 annuity for *n* yrs.	Am't of $1 in *n* yrs.	Present val. of $1 due in *n* yrs.	Am't of $1 per annum in *n* yrs.	Present val. of $1 annuity for *n* yrs.
1	$1.040	.9615	1.04	1.000	$1.050	.9524	1.05	1.000
2	1.082	.9246	2.12	1.962	1.103	.9070	2.15	1.952
3	1.125	.8890	3.25	2.886	1.158	.8638	3.31	2.859
4	1.170	.8548	4.42	3.775	1.216	.8227	4.53	3.723
5	1.217	.8219	5.63	4.630	1.276	.7835	5.80	4.546
6	1.265	.7903	6.90	5.452	1.340	.7462	7.14	5.329
7	1.316	.7599	8.21	6.242	1.407	.7107	8.55	6.076
8	1.369	.7307	9.58	7.002	1.477	.6768	10.03	6.786
9	1.423	.7026	11.01	7.733	1.551	.6446	11.58	7.463
10	1.480	.6756	12.49	8.435	1.629	.6139	13.21	8.108
11	1.539	.6496	14.03	9.111	1.710	.5847	14.92	8.722
12	1.601	.6246	15.63	9.760	1.796	.5568	16.71	9.306
13	1.665	.6006	17.29	10.385	1.886	.5303	18.60	9.863
14	1.732	.5775	19.02	10.986	1.980	.5051	20.58	10.394
15	1.801	.5553	20.82	11.563	2.079	.4810	22.66	10.899
16	1.873	.5339	22.70	12.118	2.183	.4581	24.84	11.380
17	1.948	.5134	24.65	12.652	2.292	.4363	27.13	11.838
18	2.026	.4936	26.67	13.166	2.407	.4155	29.54	12.274
19	2.107	.4746	28.78	13.659	2.527	.3957	32.07	12.690
20	2.191	.4564	30.97	14.134	2.653	.3769	34.72	13.085
21	2.279	.4388	33.25	14.590	2.786	.3589	37.51	13.462
22	2.370	.4220	35.62	15.029	2.925	.3419	40.43	13.821
23	2.465	.4057	38.08	15.451	3.072	.3256	43.50	14.163
24	2.563	.3901	40.65	15.857	3.225	.3101	46.73	14.489
25	2.666	.3751	43.31	16.247	3.386	.2953	50.11	14.799
26	2.772	.3607	46.08	16.622	3.556	.2812	53.67	15.094
27	2.883	.3468	48.97	16.983	3.733	.2678	57.40	15.375
28	2.999	.3335	51.97	17.330	3.920	.2551	61.32	15.643
29	3.119	.3207	55.08	17.663	4.116	.2429	65.44	15.898
30	3.243	.3083	58.33	17.984	4.322	.2314	69.76	16.141
31	3.373	.2965	61.70	18.292	4.538	.2204	74.30	16.372
32	3.508	.2851	65.21	18.588	4.765	.2099	79.06	16.593
33	3.648	.2741	68.86	18.874	5.003	.1999	84.07	16.803
34	3.794	.2636	72.65	19.148	5.253	.1904	89.32	17.003
35	3.946	.2534	76.60	19.411	5.516	.1813	94.84	17.193
36	4.104	.2437	80.70	19.665	5.792	.1727	100.63	17.374
37	4.268	.2343	84.97	19.908	6.081	.1644	106.71	17.547
38	4.439	.2253	89.41	20.143	6.385	.1566	113.10	17.711
39	4.616	.2166	94.03	20.368	6.705	.1491	119.80	17.868
40	4.801	.2083	98.83	20.584	7.040	.1420	126.84	18.017
41	4.993	.2003	103.82	20.793	7.392	.1353	134.23	18.159
42	5.193	.1926	109.01	20.993	7.762	.1288	141.99	18.294
43	5.400	.1852	114.41	21.186	8.150	.1227	150.14	18.423
44	5.617	.1781	120.03	21.371	8.557	.1169	158.70	18.546
45	5.841	.1712	125.87	21.549	8.985	.1113	167.69	18.663
46	6.075	.1646	131.95	21.720	9.434	.1060	177.12	18.774
47	6.318	.1583	138.26	21.885	9.906	.1009	187.03	18.880
48	6.571	.1522	144.83	22.043	10.401	.0961	197.43	18.981
49	6.833	.1463	151.67	22.195	10.921	.0916	208.35	19.077
50	7.107	.1407	158.77	22.341	11.467	.0872	219.82	19.169

Compound Interest and Discount Tables

Years	Six per cent. Am't of $1 in n yrs.	Present val. of $1 due in n yrs.	Am't of $1 per annum in n yrs.	Present val. of $1 annuity for n yrs.	Years	Six per cent. Am't of $1 in n yrs.	Present val. of $1 due in n yrs.	Am't of $1 per annum in n yrs.	Present val. of $1 annuity for n yrs.
1	$1.060	.9434	1.06	1.000	26	4.549	.2198	62.71	13.783
2	1.124	.8900	2.18	1.943	27	4.822	.2074	67.53	13.003
3	1.191	.8396	3.37	2.833	28	5.112	.1956	72.64	14.211
4	1.262	.7921	4.64	3.673	29	5.418	.1846	78.06	14.406
5	1.338	.7473	5.98	4.465	30	5.743	.1741	83.80	14.591
6	1.419	.7050	7.39	5.212	31	6.088	.1643	89.89	14.765
7	1.504	.6651	8.90	5.917	32	6.453	.1550	96.34	14.929
8	1.594	.6274	10.49	6.582	33	6.841	.1462	103.18	15.084
9	1.689	.5919	12.18	7.210	34	7.251	.1379	110.43	15.230
10	1.791	.5584	13.97	7.802	35	7.686	.1301	118.12	15.368
11	1.898	.5268	15.87	8.360	36	8.147	.1227	126.27	15.498
12	2.012	.4970	17.88	8.887	37	8.636	.1158	134.90	15.621
13	2.133	.4688	20.02	9.384	38	9.154	.1092	144.06	15.737
14	2.261	.4423	22.28	9.853	39	9.704	.1031	153.76	15.846
15	2.397	.4173	24.67	10.295	40	10.286	.0972	164.05	15.949
16	2.540	.3936	27.21	10.712	41	10.903	.0917	174.95	16.046
17	2.693	.3714	29.91	11.106	42	11.557	.0865	186.51	16.138
18	2.854	.3503	32.76	11.477	43	12.250	.0816	198.76	16.225
19	3.026	.3305	35.79	11.828	44	12.985	.0770	211.74	16.306
20	3.207	.3118	38.99	12.158	45	13.765	.0727	225.51	16.383
21	3.400	.2942	42.39	12.470	46	14.590	.0685	240.10	16.456
22	3.604	.2775	46.00	12.764	47	15.466	.0647	255.56	16.524
23	3.820	.2618	49.82	13.042	48	16.394	.0610	271.96	16.589
24	4.049	.2470	53.86	13.303	49	17.378	.0575	289.34	16.650
25	4.292	.2330	58.16	13.550	50	18.420	.0543	307.76	16.708

These tables are an abridgement of the seven-place tables in "Annuaire pour l'an 1913," published for the Bureau of Longitudes, by Gauthier-Villars, Qnai des Grands-Augustins, 55; Paris, France.

Annual Investment Table[1]

The sum of money which must be invested at the beginning of each year for a period of 1 to 50 years to amount to $1000 at compound interest.

Years	2 Per cent.	3 Per cent.	3½ Per cent.	4 Per cent.	5 Per cent.	6 Per cent.	Years
1	$980.39	970.87	966.18	961.55	952.38	943.39	1
2	485.43	478.24	474.83	471.25	464.47	457.88	2
3	320.31	314.07	311.04	307.98	302.11	296.30	3
4	237.87	232.07	229.20	226.45	220.95	215.66	4
5	188.40	182.88	180.18	177.53	172.35	167.36	5
6	155.42	150.08	147.51	144.97	140.02	135.24	6
7	131.87	126.71	124.19	121.74	116.97	112.39	7
8	114.22	109.18	106.74	104.35	99.73	95.32	8
9	100.50	95.57	93.19	90.86	86.37	82.10	9
10	89.53	84.69	82.36	80.09	75.72	71.57	10
11	80.57	75.80	73.52	71.30	67.04	63.01	11
12	73.10	68.41	66.17	63.99	59.83	55.92	12
13	66.78	62.17	59.96	57.83	53.77	49.96	13
14	61.38	56.82	54.66	52.57	48.59	44.89	14
15	56.69	52.20	50.07	48.02	44.14	40.53	15
16	52.60	48.16	46.07	44.06	40.26	36.75	16
17	48.99	44.61	42.55	40.58	36.86	33.44	17
18	45.79	41.46	39.44	37.49	33.85	30.53	18
19	42.92	38.65	36.66	34.75	31.19	27.94	19
20	40.35	36.13	34.17	32.29	28.80	25.65	20
21	38.02	33.86	31.92	30.08	26.66	23.59	21
22	35.91	31.79	29.89	28.08	24.73	21.74	22
23	33.99	29.92	28.04	26.26	22.99	20.07	23
24	32.23	28.20	26.35	24.60	21.40	18.57	24
25	30.61	26.63	24.81	23.09	19.95	17.20	25
26	29.12	25.18	23.39	21.70	18.63	15.95	26
27	27.74	23.85	22.08	20.42	17.42	14.81	27
28	26.46	22.61	20.87	19.24	16.31	13.77	28
29	25.27	21.47	19.75	18.15	15.28	12.81	29
30	24.17	20.41	18.72	17.14	14.33	11.93	30
31	23.13	19.42	17.75	16.21	13.46	11.12	31
32	22.17	18.49	16.85	15.34	12.65	10.38	32
33	21.26	17.63	16.01	14.52	11.90	9.69	33
34	20.41	16.82	15.23	13.76	11.20	9.06	34
35	19.61	16.06	14.49	13.06	10.54	8.47	35
36	18.86	15.34	13.80	12.39	9.94	7.92	36
37	18.14	14.67	13.15	11.77	9.37	7.41	37
38	17.47	14.04	12.54	11.18	8.84	6.94	38
39	16.83	13.44	11.97	10.64	8.35	6.50	39
40	16.23	12.88	11.43	10.12	7.88	6.10	40
41	15.66	12.34	10.92	9.63	7.45	5.72	41
42	15.11	11.84	10.43	9.17	7.04	5.36	42
43	14.60	11.36	9.98	8.74	6.66	5.03	43
44	14.11	10.90	9.54	8.33	6.30	4.72	44
45	13.64	10.47	9.13	7.94	5.97	4.43	45
46	13.20	10.06	8.74	7.57	5.64	4.16	46
47	12.78	9.66	8.37	7.23	5.34	3.91	47
48	12.37	9.29	8.02	6.90	5.06	3.67	48
49	11.97	8.94	7.69	6.59	4.79	3.45	49
50	11.60	8.61	7.37	6.29	4.55	3.25	50

[1] From "Lefax," Philadelphia, Penn.

AMORTIZATION AND DEPRECIATION FORMULAS[1]

Amount of an annuity which at the end of n years will amortize a capital of \$1 (interest on annuity payments and on original capital figured at the same rate).

$$\text{Annuity} = \frac{r(1+r)^n}{(1+r)^n - 1} \cdot \$1$$

Present value of an annuity of \$1 per year, payable for n years, at the end of the year.

$$\text{Present value} = \frac{1}{r}\left[1 - \frac{1}{(1+r)^n}\right] \cdot \$1$$

The sum produced at the end of n years by placing annually \$1 at r interest, each dollar being deposited at the beginning of the year.

$$\text{Sum} = \frac{1+r}{r}[(1+r)^n - 1] \cdot \$1$$

Present worth of \$1 payable at the end of n years.

$$\text{Present worth} = \frac{\$1}{(1+r)^n}$$

Value at the end of n years of \$1 at compound interest.

$$\text{Value} = (1+r)^n \cdot \$1$$

AREAS

Triangle = base × ½ altitude

Triangle (let a, b, and c be the sides and $2s = a + b + c$)

Area $= \sqrt{s(s-a)(s-b)(s-c)}$

Trapezoid = ½ sum of the bases × the altitude

Circle $= \pi r^2$

Sphere $= 4\pi r^2 = \pi d^2$

Cylinder (total surface) $= 2\pi r^2 + 2\pi rh$ (h = height or altitude)

Cylinder (cylindrical surface only) $= \pi dh = 2\pi rh$

Cone $= \pi r^2 + 2\pi r(\frac{1}{2}\sqrt{r^2 + h^2})$

Regular polygons—where side $= s$, or r = apothem (radius of inscribed circle)

5 sides (pentagon)	$1.720477s^2$	$= 3.63271r^2$
6 sides (hexagon)	$2.598076s^2$	$= 3.46410r^2$
7 sides (heptagon)	$3.633912s^2$	$= 3.37101r^2$
8 sides (octagon)	$4.828427s^2$	$= 3.31371r^2$
9 sides (nonagon)	$6.181824s^2$	$= 3.27573r^2$
10 sides (decagon)	$7.694209s^2$	$= 3.24920r^2$
11 sides (undecagon)	$9.365640s^2$	$= 3.22993r^2$
12 sides (duodecagon)	$11.196152s^2$	$= 3.21539r^2$

for n sides, $A = \frac{n}{4}s^2 \cot \frac{180°}{n} = nr^2 \tan \frac{180°}{n}$

[1] From "Annuaire pour 1915, Bureau des Longitudes."

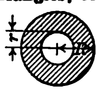
Table of Regular Polygons

No. of sides	Name of polygon	Area side = S $A = cS^2$	Radius of circumscribed circle: Perp. from center = 1	Radius of circumscribed circle: Side = 1	Radius of inscribed circle, side = 1	Length of side, radius of circum. circle = 1	Angle at center	Angle between adjacent sides
3	Triangle.....	0.4330127	2.000	0.5773	0.2887	1.7320	120°	60°
4	Square......	1.0000000	1.414	0.7071	0.5000	1.4142	90°	90°
5	Pentagon....	1.7204774	1.238	0.8506	0.6882	1.1756	72°	108°
6	Hexagon....	2.5980762	1.115	1.0000	0.8660	1.0000	60°	120°
7	Heptagon...	3.6339124	1.110	1.1524	1.0383	0.8677	51°26′	128°34′
8	Octagon.....	4.8284271	1.083	1.3066	1.2071	0.7653	45°	135°
9	Nonagon....	6.1818242	1.064	1.4619	1.3737	0.6840	40°	140°
10	Decagon....	7.6942088	1.051	1.6180	1.5388	0.6180	26°	144°
11	Undecagon..	9.3656399	1.042	1.7747	1.7028	0.5634	32°43′	147°16′21″
12	Duodecagon.	11.1961524	1.037	1.9319	1.8660	0.5176	30°	150°

Table of the Regular Polyhedrons whose Edge is Unity

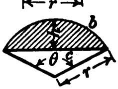
	No. of faces	Surface[1]	Volume[2]
Tetrahedron[3]..........	4	1.7320508	0.1178513
Hexahedron (cube)[3]...	6	6.0000000	1.0000000
Octahedron[3]...........	8	3.4641016	0.4717045
Dodecahedron[3]........	12	20.6457288	7.6631189
Icosahedron[3]..........	20	8.6602540	2.1816950

[1] If the edge is not unity, multiply the constant in the table by the square of the side.
[2] If the edge is not unity, multiply the constant in the table by the cube of the side.
[3] The faces of the tetrahedron, octahedron and icosahedron (20 faces) are triangles; of the hexahedron, squares; and of the dodecahedron, pentagons.



Circular Ring.—Area $= \pi(R^2 - r^2) = \pi(R - r)(R + r)$ = difference in areas between the inner and outer circles.

Quadrant.—Area $= \frac{\pi r^2}{4} = 0.7854r^2 \mp 0.3927c^2$. ($c$ = chord.)

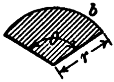


Segment.—b = length of arc. θ = angle in degrees. $c = \text{chord} = \sqrt{4(2hr - h^2)}$

$$\text{Area} = \tfrac{1}{2}[br - c(r - h)]$$

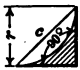
$$= \pi r^2 \frac{\theta}{360} - \frac{c(r - h)}{2}$$

When θ is greater than 180°, then $\frac{c}{2} \times$ difference between r and h is added to the fraction $\frac{\pi r^2 \theta}{360}$.

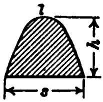


Sector.—Area $= \frac{1}{2}br = \pi r^2 \frac{\theta}{360°}$

θ = angle in degrees
b = length of arc



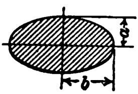
Spandrel.—Area $= 0.2146r^2 = 0.1073c^2$



Parabola.—Area $= \frac{2}{3}sh$

l = length of curved line = periphery $- s = \frac{s^2}{8h}$
$(\sqrt{c(1+c}) + 2.0326 \times \log\ (\sqrt{c} + \sqrt{1+c})$

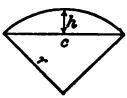
where $c = \left(\frac{4h}{s}\right)^2$



Ellipse.—Area $= \pi ab$

$$\text{Circum.} = \pi(a+b)\frac{64 - 3\left(\frac{b-a}{b+a}\right)^4}{64 - 16\left(\frac{b-a}{b+a}\right)^2}$$

[close approximation]



Sector of Sphere.—Total surface $= \frac{\pi r}{2}(4h + c)$;

$c = 2\sqrt{(2hr - h^2)}$.

$$\text{Volume} = \frac{2\pi r^2 h}{3} = \frac{2\pi r^2}{3}\left(r - \frac{\sqrt{4r^2 - c^2}}{2}\right)$$

Segment of Sphere.—Spherical surface

$$= 2\pi rh = \frac{\pi}{4}(c^2 + 4h^2)$$

$$\text{Total surface} = 2\pi rh + \frac{\pi}{4}c^2 = \frac{\pi}{2}(c^2 + 2h^2)$$

$$\text{Volume} = \pi h^2\left(r - \frac{h}{3}\right) = \pi h^2\left(\frac{c^2 + 4h^2}{8h} - \frac{h}{3}\right)$$

$$c = 2\sqrt{2hr - h^2}$$

Frustrum of Pyramid.—(Area of top and bottom, a and a' respectively).

$$\text{Volume} = \frac{h}{3}(a + a' + \sqrt{aa'})$$

Ellipsoid of Revolution.—Volume $= \frac{4\pi}{3}$ (product of the three radii).

Paraboloid of Revolution.—Volume $= \frac{\pi r^2 h}{2}$.

$$\text{Curved surface} = \frac{\pi}{6}\frac{r}{h^2}\left[(r^2 + 4h^2)^{\frac{3}{2}} - r^3\right]$$

Volumes

Cylinder $= \pi r^2 h = \frac{\pi}{4} d^2 h$

Sphere $= \frac{\pi d^3}{6} = \frac{4}{3}\pi r^3$

Cone $= \frac{1}{3}\pi r^2 h$ ($\frac{1}{3}$ the vol. of the containing cylinder)

Pyramid $= \frac{1}{3}$ base $\times$ altitude

TRIGONOMETRY

The following formulas refer to Fig. 1.

$\sin A = \frac{a}{c}$ $\cot A = \frac{b}{a}$

$\cos A = \frac{b}{c}$ $\sec A = \frac{c}{b}$

$\tan A = \frac{a}{b}$ $\operatorname{cosec} A = \frac{c}{a}$

$\operatorname{vers} A = 1 - \frac{b}{c}$ $\operatorname{covers} A = 1 - \frac{a}{c}$

$\operatorname{suvers} A = 1 + \frac{b}{c}$

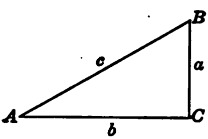


FIG. 1

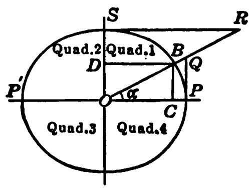


FIG. 2

Regarding the trigonometric functions as functions of the arc, rather than of the angle (see Fig. 2) we have:

$\sin \alpha = BC = OD$ $\cot \alpha = RS$

$\cos \alpha = OC = BD$ $\sec \alpha = OQ$

$\tan \alpha = PQ$ $\operatorname{cosec} \alpha = OR$

$\operatorname{vers} \alpha = CP$ $\operatorname{covers} \alpha = SD$

$\operatorname{suvers} \alpha = P'C$

The fundamental trigonometric formulæ are:

$$\sin \alpha = \frac{1}{\operatorname{cosec} \alpha} = \sqrt{1 - \cos^2 \alpha} = \frac{\tan \alpha}{\sqrt{1 + \tan^2 \alpha}} = \frac{1}{\sqrt{1 + \cot^2 \alpha}} = \frac{\sqrt{\sec^2 \alpha - 1}}{\sec \alpha}$$

$$\cos \alpha = \frac{1}{\sec \alpha} = \sqrt{1 - \sin^2 \alpha} = \frac{1}{\sqrt{1 + \tan^2 \alpha}} = \frac{\cot \alpha}{\sqrt{1 + \cot^2 \alpha}} = \frac{\sqrt{\operatorname{cosec}^2 \alpha - 1}}{\operatorname{cosec} \alpha}$$

$$\tan \alpha = \frac{1}{\cot \alpha} = \frac{\sin \alpha}{\sqrt{1 - \sin^2 \alpha}} = \frac{\sqrt{1 - \cos^2 \alpha}}{\cos \alpha} = \sqrt{\sec^2 \alpha - 1} = \frac{1}{\sqrt{\operatorname{cosec}^2 \alpha - 1}}$$

$\cot\alpha =$

$$\frac{1}{\text{ant }\alpha} = \frac{\sqrt{1-\sin^2\alpha}}{\sin\alpha} = \frac{\cos}{\sqrt{1-\cos^2\alpha}} = \frac{1}{\sqrt{\sec^2\alpha+1}} = \sqrt{\operatorname{cosec}^2\alpha-1}$$

$\sec\alpha =$

$$\frac{1}{\cos\alpha} = \frac{1}{\sqrt{1-\sin^2\alpha}} = \sqrt{1+\tan^2\alpha} = \frac{\sqrt{1+\cot^2\alpha}}{\cot\alpha} = \frac{\operatorname{cosec}\alpha}{\sqrt{\operatorname{cosec}^2\alpha-1}}$$

$\csc\alpha =$

$$\frac{1}{\sin\alpha} = \frac{1}{\sqrt{1-\cos^2\alpha}} = \frac{\sqrt{1+\tan^2\alpha}}{\tan\alpha} = \sqrt{1+\cot^2\alpha} = \frac{\sec\alpha}{\sqrt{\sec^2\alpha-1}}$$

$\sin^2\alpha + \cos^2\alpha = 1$; $\tan\alpha = \dfrac{\sin\alpha}{\cos\alpha}$; $\cot\alpha = \dfrac{\cos\alpha}{\sin\alpha}$

Rule for signs of trigonometric functions in various quadrants:

Quadrant	1	2	3	4
sin	+	+	−	−
cos	+	−	−	+
tan	+	−	+	−
cot	+	−	+	−
sec	+	−	−	+
cosec	+	+	−	−

Any function of 0° or an even multiple of 90°, $\left(\frac{\pi}{2}\right)$, plus or minus A, is the same function of A, and any function of an odd multiple of 90° is the complementary function of A, the sign being determined for the appropriate quadrant by the above table.

$$\sin(x+y) = \sin x\cos y + \cos x\sin y \quad \therefore \sin 2x = 2\sin x\cos x$$
$$\cos(x+y) = \cos x\cos y - \sin x\sin y \quad \therefore \cos 2x = \cos^2 x - \sin^2 x$$

$$\sin(x-y) = \sin x\cos y - \cos x\sin y$$
$$\cos(x-y) = \cos x\cos y + \sin x\sin y$$

$$\tan(x+y) = \frac{\tan x + \tan y}{1 - \tan x\tan y}$$

$$\tan(x-y) = \frac{\tan x - \tan y}{1 + \tan x\tan y}$$

$$\cot(x+y) = \frac{\cot x\cot y - 1}{\cot y + \cot x}$$

$$\cot(x-y) = \frac{\cot x\cot y + 1}{\cot y - \cot x}$$

$$\frac{\sin(x+y)}{\sin(x-y)} = \frac{\tan x + \tan y}{\tan x - \tan y}$$

$$\frac{\cos(x+y)}{\cos(x-y)} = \frac{1 - \tan x\tan y}{1 + \tan x\tan y}$$

$$\frac{\sin(x+y)}{\cos(x-y)} = \frac{\tan x + \tan y}{1 + \tan x \tan y}$$

$$\frac{\sin(x-y)}{\cos(x+y)} = \frac{\tan x - \tan y}{1 - \tan x \tan y}$$

$$\sin(x+y)\sin(x-y) = \sin^2 x - \sin^2 y = \cos^2 y - \cos^2 x$$

$$\cos(x+y)\cos(x-y) = \cos^2 x - \sin^2 y^2 = \cos^2 y - \sin^2 x$$

$$\sin 2x = 2 \sin x \cos x$$

$$\cos 2x = \cos^2 x - \sin^2 x = 2\cos^2 x - 1 = 1 - 2\sin^2 x$$

$$\tan 2x = \frac{2 \tan x}{1 - \tan^2 x}$$

$$\cot 2x = \frac{\cot^2 x - 1}{2 \cot x}$$

$$\sin \tfrac{1}{2}x = \sqrt{\frac{1 - \cos x}{2}}$$

$$\cos \tfrac{1}{2}x = \sqrt{\frac{1 + \cos x}{2}}$$

$$\tan \tfrac{1}{2}x = \frac{\sin x}{1 + \cos x}$$

$$\cot \tfrac{1}{2}x = \frac{\sin x}{1 - \cos x}$$

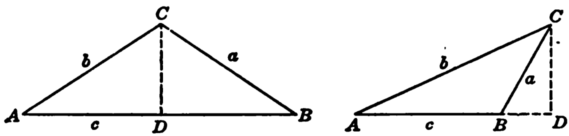
$$\sin 3x = 3 \sin x - 4 \sin^3 x$$

$$\cos 3x = 4 \cos^3 x - 3 \cos x$$

$$\tan 3x = \frac{3 \tan x - \tan^3 x}{1 - 3 \tan^2 x}$$

Solution of Triangles

The solution of the right triangle is readily deduced from the functional equations applying to Fig. 1.



The solution of oblique triangles is given in the following formula:

$$\frac{a+b}{a-b} = \frac{\sin A + \sin B}{\sin A - \sin B} = \frac{\tan \frac{1}{2}(A+B)}{\tan \frac{1}{2}(A-B)} = \frac{\cot \frac{1}{2}C}{\tan \frac{1}{2}(A-B)}$$

$$a^2 = b^2 + c^2 - 2bc \cos A \text{ or } c^2 = a^2 + b^2 - 2ac \cos C$$

$$\cos A = \frac{b^2 + c^2 - a^2}{2bc} \text{ or } \cos C = \frac{a^2 + b^2 - c^2}{2ab}$$

$$\sin \tfrac{1}{2}A = \sqrt{\frac{(a+b-c)\,(a-b+c)}{4bc}} = \sqrt{\frac{(s-a)\,(s-b)}{bc}}$$

$$\cos \tfrac{1}{2}A = \sqrt{\frac{s(s-a)}{bc}}$$

$$\tan \tfrac{1}{2}A = \sqrt{\frac{(s-b)\,(s-c)}{bc}}\sqrt{\frac{bc}{s(s-a)}}$$

$$\sin A = 2\sqrt{\frac{(s-b)\,(s-c)}{bc}}\sqrt{\frac{s(s-a)}{bc}}$$

$$\text{Area} = \frac{ab \sin C}{2} = \frac{bc \sin A}{2} = \frac{ac \sin B}{2} = \frac{b^2 \sin C \sin A}{2 \sin B} = \sqrt{s(s-a)\,(s-b)\,(s-c)}$$

$$\text{Radius of inscribed circle} = \frac{\text{area}}{\tfrac{1}{2}\text{ perimeter}}$$

$$\text{Radius of circumscribed circle} = \frac{\text{(product of the sides)}}{\text{(four times area)}}$$

Exact Numerical Value of the Functions of Some Angles

Angle	0°	30°	45°	60°	90°	120°	135°	150°	180°	270°	360°
Sine	0	$\frac{1}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{\sqrt{3}}{2}$	1	$\frac{\sqrt{3}}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{2}$	0	-1	0
Cosine	1	$\frac{\sqrt{3}}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{2}$	0	$-\frac{1}{2}$	$-\frac{1}{\sqrt{2}}$	$-\frac{\sqrt{3}}{2}$	-1	0	1
Tangent	0	$\frac{1}{\sqrt{3}}$	1	$\sqrt{3}$	∞	$-\sqrt{3}$	-1	$-\frac{1}{\sqrt{3}}$	0	∞	0
Cotangent	∞	$\sqrt{3}$	1	$\frac{1}{\sqrt{3}}$	0	$-\frac{1}{\sqrt{3}}$	-1	$-\sqrt{3}$	∞	0	∞
Secant	1	$\frac{2}{\sqrt{3}}$	$\sqrt{2}$	2	∞	-2	$-\sqrt{2}$	$-\frac{2}{\sqrt{3}}$	-1	∞	1
Cosecant	∞	2	$\sqrt{2}$	$\frac{2}{\sqrt{3}}$	1	$\frac{2}{\sqrt{3}}$	$\sqrt{2}$	2	∞	-1	∞
Versed sine	0	$\frac{2-\sqrt{3}}{2}$	$\frac{\sqrt{2}-1}{2}$	$\frac{1}{2}$	1	$\frac{3}{2}$	$\frac{1+\sqrt{2}}{\sqrt{2}}$	$\frac{2+\sqrt{3}}{2}$	2	1	0
Covers. sine	1	$\frac{1}{2}$	$\frac{\sqrt{2}-1}{\sqrt{2}}$	$\frac{2-\sqrt{3}}{2}$	0	$\frac{2-\sqrt{3}}{2}$	$\frac{\sqrt{2}-1}{\sqrt{2}}$	$\frac{1}{2}$	1	2	1

Squares, Cubes, Square and Cube Roots of Numbers from 1 to 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
1	1	1	1.0000	1.0000	51	2601	132651	7.1414	3.7084
2	4	8	1.4142	1.2599	52	2704	140608	7.2111	3.7325
3	9	27	1.7321	1.4422	53	2809	148877	7.2801	3.7563
4	16	64	2.0000	1.5874	54	2916	157464	7.3485	3.7798
5	25	125	2.2361	1.7100	55	3025	166375	7.4162	3.8030
6	36	216	2.4495	1.8171	56	3136	175616	7.4833	3.8259
7	49	343	2.6458	1.9129	57	3249	185193	7.5498	3.8485
8	64	512	2.8284	2.0000	58	3364	195112	7.6158	3.8709
9	81	729	3.0000	2.0801	59	3481	205379	7.6811	3.8930
10	100	1000	3.1623	2.1544	60	3600	216000	7.7460	3.9149
11	121	1331	3.3166	2.2240	61	3721	226981	7.8102	3.9365
12	144	1728	3.4641	2.2894	62	3844	238328	7.8740	3.9579
13	169	2197	3.6056	2.3513	63	3969	250047	7.9373	3.9791
14	196	2744	3.7417	2.4101	64	4096	262144	8.0000	4.0000
15	225	3375	3.8730	2.4662	65	4225	274625	8.0623	4.0207
16	256	4096	4.0000	2.5198	66	4356	287496	8.1240	4.0412
17	289	4913	4.1231	2.5713	67	4489	300763	8.1854	4.0615
18	324	5832	4.2426	2.6207	68	4624	314432	8.2462	4.0817
19	361	6859	4.3589	2.6684	69	4761	328509	8.3066	4.1016
20	400	8000	4.4721	2.7144	70	4900	343000	8.3666	4.1213
21	441	9261	4.5826	2.7589	71	5041	357911	8.4261	4.1408
22	484	10648	4.6904	2.8020	72	5184	373248	8.4853	4.1602
23	529	12167	4.7958	2.8439	73	5329	389017	8.5440	4.1793
24	576	13824	4.8990	2.8845	74	5476	405224	8.6023	4.1983
25	625	15625	5.0000	2.9240	75	5625	421875	8.6603	4.2172
26	676	17576	5.0990	2.9625	76	5776	438976	8.7178	4.2358
27	729	19683	5.1962	3.0000	77	5929	456533	8.7750	4.2543
28	784	21952	5.2915	3.0366	78	6084	474552	8.8318	4.2727
29	841	24389	5.3852	3.0723	79	6241	493039	8.8882	4.2908
30	900	27000	5.4772	3.1072	80	6400	512000	8.9443	4.3089
31	961	29791	5.5678	3.1414	81	6561	531441	9.0000	4.3267
32	1024	32768	5.6569	3.1748	82	6724	551368	9.0554	4.3445
33	1089	35937	5.7446	3.2075	83	6889	571787	9.1104	4.3621
34	1156	39304	5.8310	3.2396	84	7056	592704	9.1652	4.3795
35	1225	42875	5.9161	3.2711	85	7225	614125	9.2195	4.3968
36	1296	46656	6.0000	3.3019	86	7396	636056	9.2736	4.4140
37	1369	50653	6.0828	3.3322	87	7569	658503	9.3276	4.4310
38	1444	54872	6.1644	3.3620	88	7744	681472	9.3808	4.4480
39	1521	59319	6.2450	3.3912	89	7921	704969	9.4340	4.4647
40	1600	64000	6.3246	3.4200	90	8100	729000	9.4868	4.4814
41	1681	68921	6.4031	3.4482	91	8281	753571	9.5394	4.4979
42	1764	74088	6.4807	3.4760	92	8464	778688	9.5917	4.5144
43	1849	79507	6.5574	3.5034	93	8649	804357	9.6437	4.5307
44	1936	85184	6.6332	3.5303	94	8836	830584	9.6954	4.5468
45	2025	91125	6.7082	3.5569	95	9025	857375	9.7468	4.5629
46	2116	97336	6.7823	3.5830	96	9216	884736	9.7980	4.5789
47	2209	103823	6.8557	3.6088	97	9409	912673	9.8489	4.5947
48	2304	110592	6.9282	3.6342	98	9604	941192	9.8995	4.6104
49	2401	117649	7.0000	3.6593	99	9801	970299	9.9499	4.6261
50	2500	125000	7.0711	3.6840	100	10000	1000000	10.0000	4.6416

Squares, Cubes, Square and Cube Roots of Numbers from 1 to 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
101	10201	1030301	10.0499	4.6570	151	22801	3442951	12.2882	5.3251
102	10404	1061208	10.0995	4.6723	152	23104	3511808	12.3288	5.3368
103	10609	1092727	10.1489	4.6875	153	23409	3581577	12.3693	5.3485
104	10816	1124864	10.1980	4.7027	154	23716	3652264	12.4097	5.3601
105	11025	1157625	10.2470	4.7177	155	24025	3723875	12.4499	5.3717
106	11236	1191016	10.2956	4.7326	156	24336	3796416	12.4900	5.3832
107	11449	1225043	10.3441	4.7475	157	24649	3869893	12.5300	5.3947
108	11664	1259712	10.3923	4.7622	158	24964	3944312	12.5698	5.4061
109	11881	1295029	10.4403	4.7769	159	25281	4019679	12.6095	5.4175
110	12100	1331000	10.4881	4.7914	160	25600	4096000	12.6491	5.4288
111	12321	1367631	10.5357	4.8059	161	25921	4173281	12.6886	5.4401
112	12544	1404928	10.5830	4.8203	162	26244	4251528	12.7279	5.4514
113	12769	1442897	10.6301	4.8346	163	26569	4330747	12.7671	5.4626
114	12996	1481544	10.6771	4.8488	164	26896	4410944	12.8062	5.4737
115	13225	1520875	10.7238	4.8629	165	27225	4492125	12.8452	5.4848
116	13456	1560896	10.7703	4.8770	166	27556	4574296	12.8841	5.4959
117	13689	1601613	10.8167	4.8910	167	27889	4657463	12.9228	5.5069
118	13924	1643032	10.8628	4.9049	168	28224	4741632	12.9615	5.5178
119	14161	1685159	10.9087	4.9187	169	28561	4826809	13.0000	5.5288
120	14400	1728000	10.9545	4.9324	170	28900	4913000	13.0384	5.5397
121	14641	1771561	11.0000	4.9461	171	29241	5000211	13.0767	5.5505
122	14884	1815848	11.0454	4.9597	172	29584	5088448	13.1149	5.5613
123	15129	1860867	11.0905	4.9732	173	29929	5177717	13.1529	5.5721
124	15376	1906624	11.1355	4.9866	174	30276	5268024	13.1909	5.5828
125	15625	1953125	11.1803	5.0000	175	30625	5359375	13.2288	5.5034
126	15876	2000376	11.2250	5.0133	176	30976	5451776	13.2665	5.6041
127	16129	2048383	11.2694	5.0265	177	31329	5545233	13.3041	5.6147
128	16384	2097152	11.3137	5.0397	178	31684	5639752	13.3417	5.6252
129	16641	2146689	11.3578	5.0528	179	32041	5735339	13.3791	5.6357
130	16900	2197000	11.4018	5.0658	180	32400	5832000	13.4164	5.6462
131	17161	2248091	11.4455	5.0788	181	32761	5929741	13.4536	5.6567
132	17424	2299968	11.4891	5.0916	182	33124	6028568	13.4907	5.6671
133	17689	2352637	11.5326	5.1045	183	33489	6128487	13.5277	5.6774
134	17956	2406104	11.5758	5.1172	184	33856	6229504	13.5647	5.6877
135	18225	2460375	11.6190	5.1299	185	34225	6331625	13.6015	5.6980
136	18496	2515456	11.6619	5.1426	186	34596	6434856	13.6382	5.7083
137	18769	2571353	11.7047	5.1551	187	34969	6539203	13.6748	5.7185
138	19044	2628072	11.7473	5.1676	188	35344	6644672	13.7113	5.7287
139	19321	2685619	11.7898	5.1801	189	35721	6751269	13.7477	5.7388
140	19600	2744000	11.8322	5.1925	190	36100	6859000	13.7840	5.7489
141	19881	2803221	11.8743	5.2048	191	36481	6967871	13.8203	5.7590
142	20164	2863288	11.9164	5.2171	192	36864	7077888	13.8564	5.7690
143	20449	2924207	11.9583	5.2293	193	37249	7189057	13.8924	5.7790
144	20736	2985984	12.0000	5.2415	194	37636	7301384	13.9284	5.7890
145	21025	3048625	12.0416	5.2536	195	38025	7414875	13.9642	5.7089
146	21316	3112136	12.0830	5.2656	196	38416	7529536	14.0000	5.8088
147	21609	3176523	12.1244	5.2776	197	38809	7645373	14.0357	5.8186
148	21904	3241792	12.1655	5.2896	198	39204	7762392	14.0712	5.8285
149	22201	3307049	12.2066	5.3015	199	39601	7880599	14.1067	5.8383
150	22500	3375000	12.2474	5.3133	200	40000	8000000	14.1421	5.8480

SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS FROM 1 TO 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
201	40401	8120601	14.1774	5.8578	251	63001	15813251	15.8430	6.3080
202	40804	8242408	14.2127	5.8675	252	63504	16003008	15.8745	6.3164
203	41209	8365427	14.2478	5.8771	253	64009	16194277	15.9060	6.3247
204	41616	8489664	14.2829	5.8868	254	64516	16387064	15.9374	6.3330
205	42025	8615125	14.3178	5.8964	255	65025	16581375	15.9687	6.3413
206	42436	8741816	14.3527	5.9059	256	65536	16777216	16.0000	6.3496
207	42849	8869743	14.3875	5.9155	257	66049	16974593	16.0312	6.3579
208	43264	8998912	14.4222	5.9250	258	66564	17173512	16.0624	6.3661
209	43681	9129329	14.4568	5.9345	259	67081	17373979	16.0935	6.3743
210	44100	9261000	14.4914	5.9439	260	67600	17576000	16.1245	6.3825
211	44521	9393931	14.5258	5.9533	261	68121	17779581	16.1555	6.3907
212	44944	9528128	14.5602	5.9627	262	68644	17984728	16.1864	6.3988
213	45369	9663597	14.5945	5.9721	263	69169	18191447	16.2173	6.4070
214	45796	9800344	14.6287	5.9814	264	69696	18399744	16.2481	6.4151
215	46225	9938375	14.6629	5.9907	265	70225	18609625	16.2788	6.4232
216	46656	10077696	14.6969	6.0000	266	70756	18821096	16.3095	6.4312
217	47089	10218313	14.7309	6.0092	267	71289	19034163	16.3401	6.4393
218	47524	10360232	14.7648	6.0185	268	71824	19248832	16.3707	6.4473
219	47961	10503459	14.7986	6.0277	269	72361	19465109	16.4012	6.4553
220	48400	10648000	14.8324	6.0368	270	72900	19683000	16.4317	6.4633
221	48841	10793861	14.8661	6.0459	271	73441	19902511	16.4621	6.4713
222	49284	10941048	14.8997	6.0550	272	73984	20123648	16.4924	6.4792
223	49729	11089567	14.9332	6.0641	273	74529	20346417	16.5227	6.4872
224	50176	11239424	14.9666	6.0732	274	75076	20570824	16.5529	6.4951
225	50625	11390625	15.0000	6.0822	275	75625	20796875	16.5831	6.5030
226	51076	11543176	15.0333	6.0912	276	76176	21024576	16.6132	6.5108
227	51529	11697083	15.0665	6.1002	277	76729	21253933	16.6433	6.5187
228	51984	11852352	15.0997	6.1091	278	77284	21484952	16.6733	6.5265
229	52441	12008989	15.1327	6.1180	279	77841	21717639	16.7033	6.5343
230	52900	12167000	15.1658	6.1269	280	78400	21952000	16.7332	6.5421
231	53361	12326391	15.1987	6.1358	281	78961	22188041	16.7631	6.5499
232	53824	12487168	15.2315	6.1446	282	79524	22425768	16.7929	6.5577
233	54289	12649337	15.2643	6.1534	283	80089	22665187	16.8226	6.5654
234	54756	12812904	15.2971	6.1622	284	80656	22906304	16.8523	6.5731
235	55225	12977875	15.3297	6.1710	285	81225	23149125	16.8819	6.5808
236	55696	13144256	15.3623	6.1797	286	81796	23393656	16.9115	6.5885
237	56169	13312053	15.3948	6.1885	287	82369	23639903	16.9411	6.5962
238	56644	13481272	15.4272	6.1972	288	82944	23887872	16.9706	6.6039
239	57121	13651919	15.4596	6.2058	289	83521	24137569	17.0000	6.6115
240	57600	13824000	15.4919	6.2145	290	84100	24389000	17.0294	6.6191
241	58081	13997521	15.5242	6.2231	291	84681	24642171	17.0587	6.6267
242	58564	14172488	15.5563	6.2317	292	85264	24897088	17.0880	6.6343
243	59049	14348907	15.5885	6.2403	293	85849	25153757	17.1172	6.6419
244	59536	14526784	15.6205	6.2488	294	86436	25412184	17.1464	6.6494
245	60025	14706125	15.6525	6.2573	295	87025	25672375	17.1756	6.6569
246	60516	14886936	15.6844	6.2658	296	87616	25934336	17.2047	6.6644
247	61009	15069223	15.7162	6.2743	297	88209	26198073	17.2337	6.6719
248	61504	15252992	15.7480	6.2828	298	88804	26463592	17.2627	6.6794
249	62001	15438249	15.7797	6.2912	299	89401	26730899	17.2916	6.6869
250	62500	15625000	15.8114	6.2996	300	90000	27000000	17.3205	6.6943

Squares, Cubes, Square and Cube Roots of Numbers from 1 to 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
301	90601	27270901	17.3494	6.7018	351	123201	43243551	18.7350	7.0540
302	91204	27543608	17.3781	6.7092	352	123904	43614208	18.7617	7.0607
303	91809	27818127	17.4069	6.7166	353	124609	43986977	18.7883	7.0674
304	92416	28094464	17.4356	6.7240	354	125316	44361864	18.8149	7.0740
305	93025	28372625	17.4642	6.7313	355	126025	44738875	18.8414	7.0807
306	93636	28652616	17.4929	6.7387	356	126736	45118016	18.8680	7.0873
307	94249	28934443	17.5214	6.7460	357	127449	45499293	18.8944	7.0940
308	94864	29218112	17.5499	6.7533	358	128164	45882712	18.9209	7.1006
309	95481	29503629	17.5784	6.7606	359	128881	46268279	18.9473	7.1072
310	96100	29791000	17.6068	6.7679	360	129600	46656000	18.9737	7.1138
311	96721	30080231	17.6352	6.7752	361	130321	47045881	19.0000	7.1204
312	97344	30371328	17.6635	6.7824	362	131044	47437928	19.0263	7.1269
313	97969	30664297	17.6918	6.7897	363	131769	47832147	19.0526	7.1335
314	98596	30959144	17.7200	6.7969	364	132496	48228544	19.0788	7.1400
315	99225	31255875	17.7482	6.8041	365	133225	48627125	19.1050	7.1466
316	99856	31554496	17.7764	6.8113	366	133956	49027896	19.1311	7.1531
317	100489	31855013	17.8045	6.8185	367	134689	49430863	19.1572	7.1596
318	101124	32157432	17.8326	6.8256	368	135424	49836032	19.1833	7.1661
319	101761	32461759	17.8606	6.8328	369	136161	50243409	19.2094	7.1726
320	102400	32768000	17.8885	6.8399	370	136900	50653000	19.2354	7.1791
321	103041	33076161	17.9165	6.8470	371	137641	51064811	19.2614	7.1855
322	103684	33386248	17.9444	6.8541	372	138384	51478848	19.2873	7.1920
323	104329	33698267	17.9722	6.8612	373	139129	51895117	19.3132	7.1984
324	104976	34012224	18.0000	6.8683	374	139876	52313624	19.3391	7.2048
325	105625	34328125	18.0278	6.8753	375	140625	52734375	19.3649	7.2112
326	106276	34645976	18.0555	6.8824	376	141376	53157376	19.3907	7.2177
327	106929	34965783	18.0831	6.8894	377	142129	53582633	19.4165	7.2240
328	107584	35287552	18.1108	6.8964	378	142884	54010152	19.4422	7.2304
329	108241	35611289	18.1384	6.9034	379	143641	54439939	19.4679	7.2368
330	108900	35937000	18.1659	6.9104	380	144400	54872000	19.4936	7.2432
331	109561	36264691	18.1934	6.9174	381	145161	55306341	19.5192	7.2495
332	110224	36594368	18.2209	6.9244	382	145924	55742968	19.5448	7.2558
333	110889	36926037	18.2483	6.9313	383	146689	56181887	19.5704	7.2622
334	111556	37259704	18.2757	6.9382	384	147456	56623104	19.5959	7.2685
335	112225	37595375	18.3030	6.9451	385	148225	57066625	19.6214	7.2748
336	112896	37933056	18.3303	6.9521	386	148996	57512456	19.6469	7.2811
337	113569	38272753	18.3576	6.9589	387	149769	57960603	19.6723	7.2874
338	114244	38614472	18.3848	6.9658	388	150544	58411072	19.6977	7.2936
339	114921	38958219	18.4120	6.9727	389	151321	58863869	19.7231	7.2999
340	115600	39304000	18.4391	6.9795	390	152100	59319000	19.7484	7.3061
341	116281	39651821	18.4662	6.9864	391	152881	59776471	19.7737	7 3124
342	116964	40001688	18.4932	6.9932	392	153664	60236288	19.7990	7.3186
343	117649	40353607	18.5203	7.0000	393	154449	60698457	19.8242	7.3248
344	118336	40707584	18.5472	7.0068	394	155236	61162984	19.8494	7.3310
345	119025	41063625	18.5742	7.0136	395	156025	61629875	19.8746	7.3372
346	119716	41421736	18.6011	7.0203	396	156816	62099136	19.8997	7.3434
347	120409	41781923	18.6279	7.0271	397	157609	62570773	19.9249	7.3496
348	121104	42144192	18.6548	7.0338	398	158404	63044792	19.9499	7.3558
349	121801	42508549	18.6815	7.0406	399	159201	63521199	19.9750	7.3619
350	122500	42875000	18.7083	7.0473	400	160000	64000000	20.0000	7.3681

SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS FROM 1 TO 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
401	160801	64481201	20.0250	7.3742	451	203401	91733851	21.2368	7.6688
402	161604	64964808	20.0499	7.3803	452	204304	92345408	21.2603	7.6744
403	162409	65450827	20.0749	7.3864	453	205209	92959677	21.2838	7.6800
404	163216	65939264	20.0998	7.3925	454	206116	93576664	21.3073	7.6857
405	164025	66430125	20.1246	7.3986	455	207025	94196375	21.3307	7.6914
406	164836	66923416	20.1494	7.4047	456	207936	94818816	21.3542	7.6970
407	165649	67419143	20.1742	7.4108	457	208849	95443993	21.3776	7.7026
408	166464	67917312	20.1990	7.4169	458	209764	96071912	21.4009	7.7082
409	167281	68417929	20.2237	7.4229	459	210681	96702579	21.4243	7.7138
410	168100	68921000	20.2485	7.4290	460	211600	97336000	21.4476	7.7194
411	168921	69426531	20.2731	7.4350	461	212521	97972181	21.4709	7.7250
412	169744	69934528	20.2978	7.4410	462	213444	98611128	21.4942	7.7306
413	170569	70444997	20.3224	7.4470	463	214369	99252847	21.5174	7.7362
414	171396	70957944	20.3470	7.4530	464	215296	99897344	21.5407	7.7418
415	172225	71473375	20.3715	7.4590	465	216225	100544625	21.5639	7.7473
416	173056	71991296	20.3961	7.4650	466	217156	101194696	21.5870	7.7529
417	173889	72511713	20.4206	7.4710	467	218089	101847563	21.6102	7.7584
418	174724	73034632	20.4450	7.4770	468	219024	102503232	21.6333	7.7639
419	175561	73560059	20.4695	7.4829	469	219961	103161709	21.6564	7.7695
420	176400	74088000	20.4939	7.4889	470	220900	103823000	21.6795	7.7750
421	177241	74618461	20.5183	7.4948	471	221841	104487111	21.7025	7.7805
422	178084	75151448	20.5426	7.5007	472	222784	105154048	21.7256	7.7860
423	178929	75686967	20.5670	7.5067	473	223729	105823817	21.7486	7.7915
424	179776	76225024	20.5913	7.5126	474	224676	106496424	21.7715	7.7970
425	180625	76765625	20.6155	7.5185	475	225625	107171875	21.7945	7.8025
426	181476	77308776	20.6398	7.5244	476	226576	107850176	21.8174	7.8079
427	182329	77854483	20.6640	7.5302	477	227529	108531333	21.8403	7.8134
428	183184	78402752	20.6882	7.5361	478	228484	109215352	21.8632	7.8188
429	184041	78953589	20.7123	7.5420	479	229441	109902239	21.8861	7.8243
430	184900	79507000	20.7364	7.5478	480	230400	110592000	21.9089	7.8297
431	185761	80062991	20.7605	7.5537	481	231361	111284641	21.9317	7.8352
432	186624	80621568	20.7846	7.5595	482	232324	111980168	21.9545	7.8406
433	187489	81182737	20.8087	7.5654	483	233289	112678587	21.9773	7.8460
434	188356	81746504	20.8327	7.5712	484	234256	113379904	22.0000	7.8514
435	189225	82312875	20.8567	7.5770	485	235225	114084125	22.0227	7.8568
436	190096	82881856	20.8806	7.5828	486	236196	114791256	22.0454	7.8622
437	190969	83453453	20.9045	7.5886	487	237169	115501303	22.0681	7.8676
438	191844	84027672	20.9284	7.5944	488	238144	116214272	22.0907	7.8730
439	192721	84604519	20.9523	7.6001	489	239121	116930169	22.1133	7.8784
440	193600	85184000	20.9762	7.6059	490	240100	117649000	22.1359	7.8837
441	194481	85766121	21.0000	7.6117	491	241081	118370771	22.1585	7.8891
442	195364	86350888	21.0238	7.6174	492	242064	119095488	22.1811	7.8944
443	196249	86938307	21.0476	7.6232	493	243049	119823157	22.2036	7.8998
444	197136	87528384	21.0713	7.6289	494	244036	120553784	22.2261	7.9051
445	198025	88121125	21.0950	7.6346	495	245025	121287375	22.2486	7.9105
446	198916	88716536	21.1187	7.6403	496	246016	122023936	22.2711	7.9158
447	199809	89314623	21.1424	7.6460	497	247009	122763473	22.2935	7.9211
448	200704	89915392	21.1660	7.6517	498	248004	123505992	22.3159	7.9264
449	201601	90518849	21.1896	7.6574	499	249001	124251499	22.3383	7.9317
450	202500	91125000	21.2132	7.6631	500	250000	125000000	22.3607	7.9370

Squares, Cubes, Square and Cube Roots of Numbers from 1 to 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
501	251001	125751501	22.3830	7.9423	551	303601	167284151	23.4734	8.1982
502	252004	126506008	22.4054	7.9476	552	304704	168196608	23.4947	8.2031
503	253009	127263527	22.4277	7.9528	553	305809	169112377	23.5160	8.2081
504	254016	128024064	22.4499	7.9581	554	306916	170031464	23.5372	8.2130
505	255025	128787625	22.4722	7.9634	555	308025	170953875	23.5584	8.2180
506	256036	129554216	22.4944	7.9686	556	309136	171879616	23.5797	8.2229
507	257049	130323843	22.5167	7.9739	557	310249	172808693	23.6008	8.2278
508	258064	131096512	22.5389	7.9791	558	311364	173741112	23.6220	8.2327
509	259081	131872229	22.5610	7.9843	559	312481	174676879	23.6432	8.2377
510	260100	132651000	22.5832	7.9896	560	313600	175616000	23.6643	8.2426
511	261121	133432831	22.6053	7.9948	561	314721	176558481	23.6854	8.2475
512	262144	134217728	22.6274	8.0000	562	315844	177504328	23.7065	8.2524
513	263169	135005697	22.6495	8.0052	563	316969	178453547	23.7276	8.2573
514	264196	135796744	22.6716	8.0104	564	318096	179406144	23.7487	8.2621
515	265225	136590875	22.6936	8.0156	565	319225	180362125	23.7697	8.2670
516	266256	137388096	22.7156	8.0208	566	320356	181321496	23.7908	8.2719
517	267289	138188413	22.7376	8.0260	567	321489	182284263	23.8118	8.2768
518	268324	138991832	22.7596	8.0311	568	322624	183250432	23.8328	8.2816
519	269361	139798359	22.7816	8.0363	569	323761	184220009	23.8537	8.2865
520	270400	140608000	22.8035	8.0415	570	324900	185193000	23.8747	8.2913
521	271441	141420761	22.8254	8.0466	571	326041	186169411	23.8956	8.2962
522	272484	142236648	22.8473	8.0517	572	327184	187149248	23.9165	8.3010
523	273529	143055667	22.8692	8.0569	573	328329	188132517	23.9374	8.3059
524	274576	143877824	22.8910	8.0620	574	329476	189119224	23.9583	8.3107
525	275625	144703125	22.9129	8.0671	575	330625	190109375	23.9792	8.3155
526	276676	145531576	22.9347	8.0723	576	331776	191102976	24.0000	8.3203
527	277729	146363183	22.9565	8.0774	577	332929	192100033	24.0208	8.3251
528	278784	147197952	22.9783	8.0825	578	334084	193100552	24.0416	8.3300
529	279841	148035889	23.0000	8.0876	579	335241	194104539	24.0624	8.3348
530	280900	148877000	23.0217	8.0927	580	336400	195112000	24.0832	8.3396
531	281961	149721291	23.0434	8.0978	581	337561	196122941	24.1039	8.3443
532	283024	150568768	23.0651	8.1028	582	338724	197137368	24.1247	8.3491
533	284089	151419437	23.0868	8.1079	583	339889	198155287	24.1454	8.3539
534	285156	152273304	23.1084	8.1130	584	341056	199176704	24.1661	8.3587
535	286225	153130375	23.1301	8.1180	585	342225	200201625	24.1868	8.3624
536	287296	153990656	23.1517	8.1231	586	343396	201230056	24.2074	8.3682
537	288369	154854153	23.1733	8.1281	587	344569	202262003	24.2281	8.3730
538	289444	155720872	23.1948	8.1332	588	345744	203297472	24.2487	8.3777
539	290521	156590819	23.2164	8.1382	589	346921	204336469	24.2693	8.3825
540	291600	157464000	23.2379	8.1433	590	348100	205379000	24.2899	8.3872
541	292681	158340421	23.2594	8.1483	591	349281	206425071	24.3105	8.3919
542	293764	159220088	23.2809	8.1533	592	350464	207474688	24.3311	8.3967
543	294849	160103007	23.3024	8.1583	593	351649	208527857	24.3516	8.4014
544	295936	160989184	23.3238	8.1633	594	352836	209584584	24.3721	8.4061
545	297025	161878625	23.3452	8.1683	595	354025	210644875	24.3926	8.4108
546	298116	162771336	23.3666	8.1733	596	355216	211708736	24.4131	8.4155
547	299209	163667323	23.3880	8.1783	597	356409	212776173	24.4336	8.4202
548	300304	164566592	23.4094	8.1833	598	357604	213847192	24.4540	8.4249
549	301401	165469149	23.4307	8.1882	599	358801	214921799	24.4715	8.4296
550	302500	166375000	23.4521	8.1932	600	360000	216000000	24.4949	8.4343

SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS FROM 1 TO 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
601	361201	217081801	24.5153	8.4390	651	423801	275894451	25.5147	8.6668
602	362404	218167208	24.5357	8.4437	652	425104	277167808	25.5343	8.6713
603	363609	219256227	24.5561	8.4484	653	426409	278445077	25.5539	8.6757
604	364816	220348864	24.5764	8.4530	654	427716	279726264	25.5734	8.6801
605	366025	221445125	24.5967	8.4577	655	429025	281011375	25.5930	8.6845
606	367236	222545016	24.6171	8.4623	656	430336	282300416	25.6125	8.6890
607	368449	223648543	24.6374	8.4670	657	431649	283593393	25.6320	8.6934
608	369664	224755712	24.6577	8.4716	658	432964	284890312	25.6515	8.6978
609	370881	225866529	24.6779	8.4763	659	434281	286191179	25.6710	8.7022
610	372100	226981000	24.6982	8.4809	660	435600	287496000	25.6905	8.7066
611	373321	228099131	24.7184	8.4856	661	436921	288804781	25.7099	8.7110
612	374544	229220928	24.7386	8.4902	662	438244	290117528	25.7294	8.7154
613	375769	230346397	24.7588	8.4948	663	439569	291434247	25.7488	8.7198
614	376996	231475544	24.7790	8.4994	664	440896	292754944	25.7682	8.7241
615	378225	232608375	24.7992	8.5040	665	442225	294079625	25.7876	8.7285
616	379456	233744896	24.8193	8.5086	666	443556	295408296	25.8070	8.7329
617	380689	234885113	24.8395	8.5132	667	444889	296740963	25.8263	8.7373
618	381924	236029032	24.8596	8.5178	668	446224	298077632	25.8457	8.7416
619	383161	237176659	24.8797	8.5224	669	447561	299418309	25.8650	8.7460
620	384400	238328000	24.8998	8.5270	670	448900	300763000	25.8844	8.7503
621	385641	239483061	24.9199	8.5316	671	450241	302111711	25.9037	8.7547
622	386884	240641848	24.9399	8.5362	672	451584	303464448	25.9230	8.7590
623	388129	241804367	24.9600	8.5408	673	452929	304821217	25.9422	8.7634
624	389376	242970624	24.9800	8.5453	674	454276	306182024	25.9615	8.7677
625	390625	244140625	25.0000	8.5499	675	455625	307546875	25.9808	8.7721
626	391876	245314376	25.0200	8.5544	676	456976	308915776	26.0000	8.7764
627	393129	246491883	25.0400	8.5590	677	458329	310288733	26.0192	8.7807
628	394384	247673152	25.0599	8.5635	678	459684	311665752	26.0384	8.7850
629	395641	248858189	25.0799	8.5681	679	461041	313046839	26.0576	8.7893
630	396900	250047000	25.0998	8.5726	680	462400	314432000	26.0768	8.7937
631	398161	251239591	25.1197	8.5772	681	463761	315821241	26.0960	8.7980
632	399424	252435968	25.1396	8.5817	682	465124	317214568	26.1151	8.8023
633	400689	253636137	25.1595	8.5862	683	466489	318611987	26.1343	8.8066
634	401956	254840104	25.1794	8.5907	684	467856	320013504	26.1534	8.8109
635	403225	256047875	25.1992	8.5952	685	469225	321419125	26.1725	8.8152
636	404496	257259456	25.2190	8.5997	686	470596	322828856	26.1916	8.8194
637	405769	258474853	25.2389	8.6043	687	471969	324242703	26.2107	8.8237
638	407044	259694072	25.2587	8.6088	688	473344	325660672	26.2298	8.8280
639	408321	260917119	25.2784	8.6132	689	474721	327082769	26.2488	8.8323
640	409600	262144000	25.2982	8.6177	690	476100	328509000	26.2679	8.8366
641	410881	263374721	25.3180	8.6222	691	477481	329939371	26.2869	8.8408
642	412164	264609288	25.3377	8.6267	692	478864	331373888	26.3059	8.8451
643	413449	265847707	25.3574	8.6312	693	480249	332812557	26.3249	8.8493
644	414736	267089984	25.3772	8.6357	694	481636	334255384	26.3439	8.8536
645	416025	268336125	25.3969	8.6401	695	483025	335702375	26.3629	8.8578
646	417316	269586136	25.4165	8.6446	696	484416	337153536	26.3818	8.8621
647	418609	270840023	25.4362	8.6490	697	485809	338608873	26.4008	8.8663
648	419904	272097792	25.4558	8.6535	698	487204	340068392	26.4197	8.8706
649	421201	273359449	25.4755	8.6579	699	488601	341532099	26.4386	8.8748
650	422500	274625000	25.4951	8.6624	700	490000	343000000	26.4575	8.8790

SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS FROM 1 TO 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
701	491401	344472101	26.4764	8.8833	751	564001	423564751	27.4044	9.0896
702	492804	345948408	26.4953	8.8875	752	565504	425259008	27.4226	9.0937
703	494209	347428927	26.5141	8.8917	753	567009	426957777	27.4408	9.0977
704	495616	348913664	26.5330	8.8959	754	568516	428661064	27.4591	9.1017
705	497025	350402625	26.5518	8.9001	755	570025	430368875	27.4773	9.1057
706	498436	351895816	26.5707	8.9043	756	571536	432081216	27.4955	9.1098
707	499849	353393243	26.5895	8.9085	757	573049	433798093	27.5136	9.1138
708	501264	354894912	26.6083	8.9127	758	574564	435519512	27.5318	9.1178
709	502681	356400829	26.6271	8.9169	759	576081	437245479	27.5500	9.1218
710	504100	357911000	26.6458	8.9211	760	577600	438976000	27.5681	9.1258
711	505521	359425431	26.6646	8.9253	761	579121	440711081	27.5862	9.1298
712	506944	360944128	26.6833	8.9295	762	580644	442450728	27.6043	9.1338
713	508369	362467097	26.7021	8.9337	763	582169	444194947	27.6225	9.1378
714	509796	363994344	26.7208	8.9378	764	583696	445943744	27.6405	9.1418
715	511225	365525875	26.7395	8.9420	765	585225	447697125	27.6586	9.1458
716	512656	367061696	26.7582	8.9462	766	586756	449455096	27.6767	9.1498
717	514089	368601813	26.7769	8.9503	767	588289	451217663	27.6948	9.1537
718	515524	370146232	26.7955	8.9545	768	589824	452984832	27.7128	9.1577
719	516961	371694959	26.8142	8.9587	769	591361	454756609	27.7308	9.1617
720	518400	373248000	26.8328	8.9628	770	592900	456533000	27.7489	9.1657
721	519841	374805361	26.8514	8.9670	771	594441	458314011	27.7669	9.1696
722	521284	376367048	26.8701	8.9711	772	595984	460099648	27.7849	9.1736
723	522729	377933067	26.8887	8.9752	773	597529	461889917	27.8029	9.1775
724	524176	379503424	26.9072	8.9794	774	599076	463684824	27.8209	9.1815
725	525625	381078125	26.9258	8.9835	775	600625	465484375	27.8388	9.1855
726	527076	382657176	26.9444	8.9876	776	602176	467288576	27.8568	9.1894
727	528529	384240583	26.9629	8.9918	777	603729	469097433	27.8747	9.1933
728	529984	385828352	26.9815	8.9959	778	605284	470910952	27.8927	9.1973
729	531441	387420489	27.0000	9.0000	779	606841	472729139	27.9106	9.2012
730	532900	389017000	27.0185	9.0041	780	608400	474552000	27.9285	9.2052
731	534361	390617891	27.0370	9.0082	781	609961	476379541	27.9464	9.2091
732	535824	392223168	27.0555	9.0123	782	611524	478211768	27.9643	9.2130
733	537289	393832837	27.0740	9.0164	783	613089	480048687	27.9821	9.2170
734	538756	395446904	27.0924	9.0205	784	614656	481890304	28.0000	9.2209
735	540225	397065375	27.1109	9.0246	785	616225	483736625	28.0179	9.2248
736	541696	398688256	27.1293	9.0287	786	617796	485587656	28.0357	9.2287
737	543169	400315553	27.1477	9.0328	787	619369	487443403	28.0535	9.2326
738	544644	401947272	27.1662	9.0369	788	620944	489303872	28.0713	9.2365
739	546121	403583419	27.1846	9.0410	789	622521	491169069	28.0891	9.2404
740	547600	405224000	27.2029	9.0450	790	624100	493039000	28.1069	9.2443
741	549081	406869021	27.2213	9.0491	791	625681	494913671	28.1247	9.2482
742	550564	408518488	27.2397	9.0532	792	627264	496793088	28.1425	9.2521
743	552049	410172407	27.2580	9.0572	793	628849	498677257	28.1603	9.2560
744	553536	411830784	27.2764	9.0613	794	630436	500566184	28.1780	9.2599
745	555025	413493625	27.2947	9.0654	795	632025	502459875	28.1957	9.2638
746	556516	415160936	27.3130	9.0694	796	633616	504358336	28.2135	9.2677
747	558009	416832723	27.3313	9.0735	797	635209	506261573	28.2312	9.2716
748	559504	418508992	27.3496	9.0775	798	636804	508169592	28.2489	9.2754
749	561001	420189749	27.3679	9.0816	799	638401	510082399	28.2666	9.2793
750	562500	421875000	27.3861	9.0856	800	640000	512000000	28.2843	9.2832

Squares, Cubes, Square and Cube Roots of Numbers from 1 to 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
801	641601	513922401	28.3019	9.2870	851	724201	616295051	29.1719	9.4764
802	643204	515849608	28.3196	9.2909	852	725904	618470208	29.1890	9.4801
803	644809	517781627	28.3373	9.2948	853	727609	620650477	29.2062	9.4838
804	646416	519718464	28.3549	9.2986	854	729316	622835864	29.2233	9.4875
805	648025	521660125	28.3725	9.3025	855	731025	625026375	29.2404	9.4912
806	649636	523606616	28.3901	9.3063	856	732736	627222016	29.2575	9.4949
807	651249	525557943	28.4077	9.3102	857	734449	629422793	29.2746	9.4986
808	652864	527514112	28.4253	9.3140	858	736164	631628712	29.2916	9.5023
809	654481	529475129	28.4429	9.3179	859	737881	633839779	29.3087	9.5060
810	656100	531441000	28.4605	9.3217	860	739600	636056000	29.3258	9.5097
811	657721	533411731	28.4781	9.3255	861	741321	638277381	29.3428	9.5134
812	659344	535387328	28.4956	9.3294	862	743044	640503928	29.3598	9.5171
813	660969	537367797	28.5132	9.3332	863	744769	642735647	29.3769	9.5207
814	662596	539353144	28.5307	9.3370	864	746496	644972544	29.3939	9.5244
815	664225	541343375	28.5482	9.3408	865	748225	647214625	29.4109	9.5281
816	665856	543338496	28.5657	9.3447	866	749956	649461896	29.4279	9.5317
817	667489	545338513	28.5832	9.3485	867	751689	651714363	29.4449	9.5354
818	669124	547343432	28.6007	9.3523	868	753424	653972032	29.4618	9.5391
819	670761	549353259	28.6182	9.3561	869	755161	656234909	29.4788	9.5427
820	672400	551368000	28.6356	9.3599	870	756900	658503000	29.4958	9.5464
821	674041	553387661	28.6531	9.3637	871	758641	660776311	29.5127	9.5501
822	675684	555412248	28.6705	9.3675	872	760384	663054848	29.5296	9.5537
823	677329	557441767	28.6880	9.3713	873	762129	665338617	29.5466	9.5574
824	678976	559476224	28.7054	9.3751	874	763876	667627624	29.5635	9.5610
825	680625	561515625	28.7228	9.3789	875	765625	669921875	29.5804	9.5647
826	682276	563559976	28.7402	9.3827	876	767376	672221376	29.5973	9.5683
827	683929	565609283	28.7576	9.3865	877	769129	674526133	29.6142	9.5719
828	685584	567663552	28.7750	9.3902	878	770884	676836152	29.6311	9.5756
829	687241	569722789	28.7924	9.3940	879	772641	679151439	29.6479	9.5792
830	688900	571787000	28.8097	9.3978	880	774400	681472000	29.6648	9.5828
831	690561	573856191	28.8271	9.4016	881	776161	683797841	29.6816	9.5865
832	692224	575930368	28.8444	9.4053	882	777924	686128968	29.6985	9.5901
833	693889	578009537	28.8617	9.4091	883	779689	688465387	29.7153	9.5937
834	695556	580093704	28.8791	9.4129	884	781456	690807104	29.7321	9.5973
835	697225	582182875	28.8964	9.4166	885	783225	693154125	29.7489	9.6010
836	698896	584277056	28.9137	9.4204	886	784996	695506456	29.7658	9.6046
837	700569	586376253	28.9310	9.4241	887	786769	697864103	29.7825	9.6082
838	702244	588480472	28.9482	9.4279	888	788544	700227072	29.7993	9.6118
839	703921	590589719	28.9655	9.4316	889	790321	702595369	29.8161	9.6154
840	705600	592704000	28.9828	9.4354	890	792100	704969000	29.8329	9.6190
841	707281	594823321	29.0000	9.4391	891	793881	707347971	29.8496	9.6226
842	708964	596947688	29.0172	9.4429	892	795664	709732288	29.8664	9.6262
843	710649	599077107	29.0345	9.4466	893	797449	712121957	29.8831	9.6298
844	712336	601211584	29.0517	9.4503	894	799236	714516984	29.8998	9.6334
845	714025	603351125	29.0689	9.4541	895	801025	716917375	29.9166	9.6370
846	715716	605495736	29.0861	9.4578	896	802816	719323136	29.9333	9.6406
847	717409	607645423	29.1033	9.4615	897	804609	721734273	29.9500	9.6442
848	719104	609800192	29.1204	9.4652	898	806404	724150792	29.9666	9.6477
849	720801	611960049	29.1376	9.4690	899	808201	726572699	29.9833	9.6513
850	722500	614125000	29.1548	9.4727	900	810000	729000000	30.0000	9.6549

SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS FROM 1 TO 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
901	811801	731432701	30.0167	9.6585	951	904401	860085351	30.8383	9.8339
902	813604	733870808	30.0333	9.6620	952	906304	862801408	30.8545	9.8374
903	815409	736314327	30.0500	9.6656	953	908209	865523177	30.8707	9.8408
904	817216	738763264	30.0666	9.6692	954	910116	868250664	30.8869	9.8443
905	819025	741217625	30.0832	9.6727	955	912025	870983875	30.9031	9.8477
906	820836	743677416	30.0998	9.6763	956	913936	873722816	30.9192	9.8511
907	822649	746142643	30.1164	9.6799	957	915849	876467493	30.9354	9.8546
908	824464	748613312	30.1330	9.6834	958	917764	879217912	30.9516	9.8580
909	826281	751089429	30.1496	9.6870	959	919681	881974079	30.9677	9.8614
910	828100	753571000	30.1662	9.6905	960	921600	884736000	30.9839	9.8648
911	829921	756058031	30.1828	9.6941	961	923521	887503681	31.0000	9.8683
912	831744	758550528	30.1993	9.6976	962	925444	890277128	31.0161	9.8717
913	833569	761048497	30.2159	9.7012	963	927369	893056347	31.0322	9.8751
914	835396	763551944	30.2324	9.7047	964	929296	895841344	31.0483	9.8785
915	837225	766060875	30.2490	9.7082	965	931225	898632125	31.0644	9.8819
916	839056	768575296	30.2655	9.7118	966	933156	901428696	31.0805	9.8854
917	840889	771095213	30.2820	9.7153	967	935089	904231063	31.0966	9.8888
918	842724	773620632	30.2985	9.7188	968	937024	907039232	31.1127	9.8922
919	844561	776151559	30.3150	9.7224	969	938961	909853209	31.1288	9.8956
920	846400	778688000	30.3315	9.7259	970	940900	912673000	31.1448	9.8990
921	848241	781229961	30.3480	9.7294	971	942841	915498611	31.1609	9.9024
922	850084	783777448	30.3645	9.7329	972	944784	918330048	31.1769	9.9058
923	851929	786330467	30.3809	9.7364	973	946729	921167317	31.1929	9.9092
924	853776	788889024	30.3974	9.7400	974	948676	924010424	31.2090	9.9126
925	855625	791453125	30.4138	9.7435	975	950625	926859375	31.2250	9.9160
926	857476	794022776	30.4302	9.7470	976	952576	929714176	31.2410	9.9194
927	859329	796597983	30.4467	9.7505	977	954529	932574833	31.2570	9.9227
928	861184	799178752	30.4631	9.7540	978	956484	935441352	31.2730	9.9261
929	863041	801765089	30.4795	9.7575	979	958441	938313739	31.2890	9.9295
930	864900	804357000	30.4959	9.7610	980	960400	941192000	31.3050	9.9329
931	866761	806954491	30.5123	9.7645	981	962361	944076141	31.3209	9.9363
932	868624	809557568	30.5287	9.7680	982	964324	946966168	31.3369	9.9396
933	870489	812166237	30.5450	9.7715	983	966289	949862087	31.3528	9.9430
934	872356	814780504	30.5614	9.7750	984	968256	952763904	31.3688	9.9464
935	874225	817400375	30.5778	9.7785	985	970225	955671625	31.3847	9.9497
936	876096	820025856	30.5941	9.7819	986	972196	958585256	31.4006	9.9531
937	877969	822656953	30.6105	9.7854	987	974169	961504803	31.4166	9.9565
938	879844	825293672	30.6268	9.7889	988	976144	964430272	31.4325	9.9598
939	881721	827936019	30.6431	9.7924	989	978121	967361669	31.4484	9.9632
940	883600	830584000	30.6594	9.7959	990	980100	970299000	31.4643	9.9666
941	885481	833237621	30.6757	9.7993	991	982081	973242271	31.4802	9.9699
942	887364	835896888	30.6920	9.8028	992	984064	976191488	31.4960	9.9733
943	889249	838561807	30.7083	9.8063	993	986049	979146657	31.5119	9.9766
944	891136	841232384	30.7246	9.8097	994	988036	982107784	31.5278	9.9800
945	893025	843908625	30.7409	9.8132	995	990025	985074875	31.5436	9.9833
946	894916	846590536	30.7571	9.8167	996	992016	988047936	31.5595	9.9866
947	896809	849278123	30.7734	9.8201	997	994009	991026973	31.5753	9.9900
948	898704	851971392	30.7896	9.8236	998	996004	994011992	31.5911	9.9933
949	900601	854670349	30.8058	9.8270	999	998001	997002999	31.6070	9.9967
950	902500	857375000	30.8221	9.8305	1000	1000000	1000000000	31.6228	10.0000

Logarithms of Numbers

N	0	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396

Logarithms of Numbers.—*Concluded*

N	0	1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745
75	8751	8456	8762	8768	8774	8779	8785	8791	8797	8802
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908
98	9912	9917	9921	9926	9930	9934	9939	9943	9941	9952
99	9956	9961	9965	9969	9974	9978	9983	9987	9998	9996

NATURAL SINES AND COSINES

NOTE.—For cosines use right-hand column of degrees and lower line of tenths.

Deg.	°0.0	°0.1	°0.2	°0.3	°0.4	°0.5	°0.6	°0.7	°0.8	°0.9	
0°	0.0000	0.0017	0.0035	0.0052	0.0070	0.0087	0.0105	0.0122	0.0140	0.0157	89
1	0.0175	0.0192	0.0209	0.0227	0.0244	0.0262	0.0279	0.0297	0.0314	0.0332	88
2	0.0349	0.0366	0.0384	0.0401	0.0419	0.0436	0.0454	0.0471	0.0488	0.0506	87
3	0.0523	0.0541	0.0558	0.0576	0.0593	0.0610	0.0628	0.0645	0.0663	0.0680	86
4	0.0698	0.0715	0.0732	0.0750	0.0767	0.0785	0.0802	0.0819	0.0837	0.0854	85
5	0.0872	0.0889	0.0906	0.0924	0.0941	0.0958	0.0976	0.0993	0.1011	0.1028	84
6	0.1045	0.1063	0.1080	0.1097	0.1115	0.1132	0.1149	0.1167	0.1184	0.1201	83
7	0.1219	0.1236	0.1253	0.1271	0.1288	0.1305	0.1323	0.1340	0.1357	0.1374	82
8	0.1392	0.1409	0.1426	0.1444	0.1461	0.1478	0.1495	0.1513	0.1530	0.1547	81
9	0.1564	0.1582	0.1599	0.1616	0.1633	0.1650	0.1668	0.1685	0.1702	0.1719	80°
10°	0.1736	0.1754	0.1771	0.1788	0.1805	0.1822	0.1840	0.1857	0.1874	0.1891	79
11	0.1908	0.1925	0.1942	0.1959	0.1977	0.1994	0.2011	0.2028	0.2045	0.2062	78
12	0.2079	0.2096	0.2113	0.2130	0.2147	0.2164	0.2181	0.2198	0.2215	0.2232	77
13	0.2250	0.2267	0.2284	0.2300	0.2317	0.2334	0.2351	0.2368	0.2385	0.2402	76
14	0.2419	0.2436	0.2453	0.2470	0.2487	0.2504	0.2521	0.2538	0.2554	0.2571	75
15	0.2588	0.2605	0.2622	0.2639	0.2656	0.2672	0.2689	0.2706	0.2723	0.2740	74
16	0.2756	0.2773	0.2790	0.2807	0.2823	0.2840	0.2857	0.2874	0.2890	0.2907	73
17	0.2924	0.2940	0.2957	0.2974	0.2990	0.3007	0.3024	0.3040	0.3057	0.3074	72
18	0.3090	0.3107	0.3123	0.3140	0.3156	0.3173	0.3190	0.3206	0.3223	0.3239	71
19	0.3256	0.3272	0.3289	0.3305	0.3322	0.3338	0.3355	0.3371	0.3387	0.3404	70°
20°	0.3420	0.3437	0.3453	0.3469	0.3486	0.3502	0.3518	0.3535	0.3551	0.3567	69
21	0.3584	0.3600	0.3616	0.3633	0.3649	0.3665	0.3681	0.3697	0.3714	0.3730	68
22	0.3746	0.3762	0.3778	0.3795	0.3811	0.3827	0.3843	0.3859	0.3875	0.3891	67
23	0.3907	0.3923	0.3939	0.3955	0.3971	0.3987	0.4003	0.4019	0.4035	0.4051	66
24	0.4067	0.4083	0.4099	0.4115	0.4131	0.4147	0.4163	0.4179	0.4195	0.4210	65
25	0.4226	0.4242	0.4258	0.4274	0.4289	0.4305	0.4321	0.4337	0.4352	0.4368	64
26	0.4384	0.4399	0.4415	0.4431	0.4446	0.4462	0.4478	0.4493	0.4509	0.4524	63
27	0.4540	0.4555	0.4571	0.4586	0.4602	0.4617	0.4633	0.4648	0.4664	0.4679	62
28	0.4695	0.4710	0.4726	0.4741	0.4756	0.4772	0.4787	0.4802	0.4818	0.4833	61
29	0.4848	0.4863	0.4879	0.4894	0.4909	0.4924	0.4939	0.4955	0.4970	0.4985	60°
30°	0.5000	0.5015	0.5030	0.5045	0.5060	0.5075	0.5090	0.5105	0.5120	0.5135	59
31	0.5150	0.5165	0.5180	0.5195	0.5210	0.5225	0.5240	0.5255	0.5270	0.5284	58
32	0.5299	0.5314	0.5329	0.5344	0.5358	0.5373	0.5388	0.5402	0.5417	0.5432	57
33	0.5446	0.5461	0.5476	0.5490	0.5505	0.5519	0.5534	0.5548	0.5563	0.5577	56
34	0.5592	0.5606	0.5621	0.5635	0.5650	0.5664	0.5678	0.5693	0.5707	0.5721	55
35	0.5736	0.5750	0.5764	0.5779	0.5793	0.5807	0.5821	0.5835	0.5850	0.5864	54
36	0.5878	0.5892	0.5906	0.5920	0.5934	0.5948	0.5962	0.5976	0.5990	0.6004	53
37	0.6018	0.6032	0.6046	0.6060	0.6074	0.6088	0.6101	0.6115	0.6129	0.6143	52
38	0.6157	0.6170	0.6184	0.6198	0.6211	0.6225	0.6239	0.6252	0.6266	0.6280	51
39	0.6293	0.6307	0.6320	0.6334	0.6347	0.6361	0.6374	0.6388	0.6401	0.6414	50°
40°	0.6428	0.6441	0.6455	0.6468	0.6481	0.6494	0.6508	0.6521	0.6534	0.6547	49
41	0.6561	0.6574	0.6587	0.6600	0.6613	0.6626	0.6639	0.6652	0.6665	0.6678	48
42	0.6691	0.6704	0.6717	0.6730	0.6743	0.6756	0.6769	0.6782	0.6794	0.6807	47
43	0.6820	0.6833	0.6845	0.6858	0.6871	0.6884	0.6896	0.6909	0.6921	0.6934	46
44	0.6947	0.6959	0.6972	0.6984	0.6997	0.7009	0.7022	0.7034	0.7046	0.7059	45
	°1.0	°0.9	°0.8	°0.7	°0.6	°0.5	°0.4	°0.3	°0.2	°0.1	Deg.

NATURAL SINES AND COSINES.—*Concluded*

Deg.	°0.0	°0.1	°0.2	°0.3	°0.4	°0.5	°0.6	°0.7	°0.8	°0.9	
45	0.7071	0.7083	0.7096	0.7108	0.7120	0.7133	0.7145	0.7157	0.7169	0.7181	44
46	0.7193	0.7206	0.7218	0.7230	0.7242	0.7254	0.7266	0.7278	0.7290	0.7302	43
47	0.7314	0.7325	0.7337	0.7349	0.7361	0.7373	0.7385	0.7396	0.7408	0.7420	42
48	0.7431	0.7443	0.7455	0.7466	0.7478	0.7490	0.7501	0.7513	0.7524	0.7536	41
49	0.7547	0.7559	0.7570	0.7581	0.7593	0.7604	0.7615	0.7627	0.7638	0.7649	40°
50°	0.7660	0.7672	0.7683	0.7694	0.7705	0.7716	9.7727	0.7738	0.7749	0.7760	39
51	0.7771	0.7782	0.7793	0.7804	0.7815	0.7826	0.7837	0.7848	0.7859	0.7869	38
52	0.7880	0.7891	0.7902	0.7912	0.7923	0.7934	0.7944	0.7955	0.7965	0.7976	37
53	0.7986	0.7997	0.8007	0.8018	0.8028	0.8039	0.8049	0.8059	0.8070	0.8080	36
54	0.8090	0.8100	0.8111	0.8121	0.8131	0.8141	0.8151	0.8161	0.8171	0.8181	35
55	0.8192	0.8202	0.8211	0.8221	0.8231	0.8241	0.8251	0.8261	0.8271	0.8281	34
56	0.8290	0.8300	0.8310	0.8320	0.8329	0.8339	0.8348	0.8358	0.8368	0.8377	33
57	0.8387	0.8396	0.8406	0.8415	0.8425	0.8434	0.8443	0.8453	0.8462	0.8471	32
58	0.8480	0.8490	0.8499	0.8508	0.8517	0.8526	0.8536	0.8545	0.8554	0.8563	31
59	0.8572	0.8581	0.8590	0.8599	0.8607	0.8616	0.8625	0.8634	0.8643	0.8652	30°
60°	0.8660	0.8669	0.8678	0.8686	0.8695	0.8704	0.8712	0.8721	0.8729	0.8738	29
61	0.8746	0.8755	0.8763	0.8771	0.8780	0.8788	0.8796	0.8805	0.8813	0.8821	28
62	0.8829	0.8838	0.8846	0.8854	0.8862	0.8870	0.8878	0.8886	0.8894	0.8902	27
63	0.8910	0.8918	0.8926	0.8934	0.8942	0.8949	0.8957	0.8965	0.8973	0.8980	26
64	0.8988	0.8996	0.9003	0.9011	0.9018	0.9026	0.9033	0.9041	0.9048	0.9056	25
65	0.9063	0.9070	0.9078	0.9085	0.9092	0.9100	0.9107	0.9114	0.9121	0.9128	24
66	0.9135	0.9143	0.9150	0.9157	0.9164	0.9171	0.9178	0.9184	0.9191	0.9198	23
67	0.9205	0.9212	0.9219	0.9225	0.9232	0.9239	0.9245	0.9252	0.9259	0.9265	22
68	0.9272	0.9278	0.9285	0.9291	0.9298	0.9304	0.9311	0.9317	0.9323	0.9330	21
69	0.9336	0.9342	0.9348	0.9354	0.9361	0.9367	0.9373	0.9379	0.9385	0.9391	20°
70°	0.9397	0.9403	0.9409	0.9415	0.9421	0.9426	0.9432	0.9438	0.9444	0.9449	19
71	0.9455	0.9461	0.9466	0.9472	0.9478	0.9483	0.9489	0.9494	0.9500	9.9505	18
72	0.9511	0.9516	0.9521	0.9527	0.9532	0.9537	0.9542	0.9548	0.9553	0.9558	17
73	0.9563	0.9568	0.9573	0.9578	0.9583	0.9588	0.9593	0.9598	0.9603	0.9608	16
74	0.9613	0.9617	0.9622	0.9627	0.9632	0.9636	0.9641	0.9646	0.9650	0.9655	15
75	0.9659	0.9664	0.9668	0.9673	0.9677	0.9681	0.9686	0.9690	0.9694	0.9699	14
76	0.9703	0.9707	0.9711	0.9715	0.9720	0.9724	0.9728	0.9732	0.9736	0.9740	13
77	0.9744	0.9748	0.9751	0.9755	0.9759	0.9763	0.9767	0.9770	0.9774	0.9778	12
78	0.9781	0.9785	0.9789	0.9792	0.9796	0.9799	0.9803	0.9806	0.9810	0.9813	11
79	0.9816	0.9820	0.9823	0.9826	0.9829	0.9833	0.9836	0.9839	0.9842	0.9845	10°
80°	0.9848	0.9851	0.9854	0.9857	0.9860	0.9863	0.9866	0.9869	0.9871	0.9874	9
81	0.9877	0.9880	0.9882	0.9885	0.9888	0.9890	0.9893	0.9895	0.9898	0.9900	8
82	0.9903	0.9905	0.9907	0.9910	0.9912	0.9914	0.9917	0.9919	0.9921	0.9923	7
83	0.9925	0.9928	0.9930	0.9932	0.9934	0.9936	0.9938	0.9940	0.9942	0.9943	6
84	0.9945	0.9947	0.9949	0.9951	0.9952	0.9954	0.9956	0.9957	0.9959	0.9960	5
85	0.9962	0.9963	0.9965	0.9966	0.9968	0.9969	0.9971	0.9972	0.9973	0.9974	4
86	0.9976	0.9977	0.9978	0.9979	0.9980	0.9981	0.9982	0.9983	0.9984	0.9985	3
87	0.9986	0.9987	0.9988	0.9989	0.9990	0.9990	0.9991	0.9992	0.9993	0.9993	2
88	0.9994	0.9995	0.9995	0.9996	0.9996	0.9997	0.9997	0.9997	0.9998	0.9998	1
89	0.9998	0.9999	0.9999	0.9999	0.9999	1.000	1.000	1.000	1.000	1.0C0	0°
	°1.0	°0.9	°0.8	°0.7	°0.6	°0.5	°0.4	°0.3	°0.2	°0.1	Deg.

NOTE.—For cosines use right-hand column of degrees and lower line of tenths.

Natural Tangents and Cotangents

Note.—For cotangents use right-hand column of degrees and lower line of tenths

Deg.	°0.0	°0.1	°0.2	°0.3	°0.4	°0.5	°0.6	°0.7	°0.8	°0.9	
0°	0.0000	0.0017	0.0035	0.0052	0.0070	0.0087	0.0105	0.0122	0.0140	0.0157	89
1	0.0175	0.0192	0.0209	0.0227	0.0244	0.0262	0.0279	0.0297	0.0314	0.0332	88
2	0.0349	0.0367	0.0384	0.0402	0.0419	0.0437	0.0454	0.0472	0.0489	0.0507	87
3	0.0524	0.0542	0.0559	0.0577	0.0594	0.0612	0.0629	0.0647	0.0664	0.0682	86
4	0.0699	0.0717	0.0734	0.0752	0.0769	0.0787	0.0805	0.0822	0.0840	0.0857	85
5	0.0875	0.0892	0.0910	0.0928	0.0945	0.0963	0.0981	0 0998	0.1016	0.1033	84
6	0.1051	0.1069	0.1086	0.1104	0.1122	0.1139	0.1157	0.1175	0.1192	0.1210	83
7	0.1228	0.1246	0.1263	0.1281	0.1299	0.1317	0.1334	0.1352	0.1370	0.1388	82
8	0.1405	0.1423	0.1441	0.1459	0.1477	0.1495	0.1512	0.1530	0.1548	0.1566	81
9	0.1584	0.1602	0.1620	0.1638	0.1655	0.1673	0.1691	0.1709	0.1727	0.1745	80°
10°	0.1763	0.1781	0.1799	0.1817	0.1835	0.1853	0.1871	0.1890	0.1908	0.1926	79
11	0.1944	0.1962	0.1980	0.1998	0.2016	0.2035	0.2053	0.2071	0.2089	0.2107	78
12	0.2126	0.2144	0.2162	0.2180	0.2199	0.2217	0.2235	0.2254	0.2272	0.2290	77
13	0.2309	0.2327	0.2345	0.2364	0.2382	0.2401	0.2419	0.2438	0.2456	0.2475	76
14	0.2493	0.2512	0.2530	0.2549	0.2568	0.2586	0.2605	0.2623	0.2642	0.2661	75
15	0.2679	0.2698	0.2717	0.2736	0.2754	0.2773	0.2792	0.2811	0.2830	0.2849	74
16	0.2867	0.2886	0.2905	0.2924	0.2943	0.2962	0.2981	0.3000	0.3019	0.3038	73
17	0.3057	0.3076	0.3096	0.3115	0.3134	0.3153	0.3172	0.3191	0.3211	0.3230	72
18	0.3249	0.3269	0.3288	0.3307	0.3327	0.3346	0.3365	0.3385	0.3404	0.3424	71
19	0.3443	0.3463	0.3482	0.3502	0.3522	0.3541	0.3561	0.3581	0.3600	0.3620	70°
20°	0.3640	0.3659	0.3679	0.3699	0.3719	0.3739	0.3759	0.3779	0.3799	0.3819	69
21	0.3839	0.3859	0.3879	0.3899	0.3919	0.3939	0.3959	0.3979	0.4000	0.4020	68
22	0.4040	0.4061	0.4081	0.4101	0.4122	0.4142	0.4163	0.4183	0.4204	0.4224	67
23	0.4245	0.4265	0.4286	0.4307	0.4327	0.4348	0.4369	0.4390	0.4411	0.4431	66
24	0.4452	0.4473	0.4494	0.4515	0.4536	0.4557	0.4578	0.4599	0.4621	0.4642	65
25	0.4663	0.4684	0.4706	0.4727	0.4748	0.4770	0.4791	0.4813	0.4834	0.4856	64
26	0.4877	0.4899	0.4921	0.4942	0.4964	0.4986	0.5008	0.5029	0.5051	0.5073	63
27	0.5095	0.5117	0.5139	0.5161	0.5184	0.5206	0.5228	0.5250	0.5272	0.5295	62
28	0.5317	0.5340	0.5362	0.5384	0.5407	0.5430	0.5452	0.5475	0.5498	0.5520	61
29	0.5543	0.5566	0.5589	0.5612	0.5635	0.5658	0.5681	0.5704	0.5727	0.5750	60°
30°	0.5774	0.5797	0.5820	0.5844	0.5867	0.5890	0.5914	0.5938	0.5961	0.5985	59
31	0.6009	0.6032	0.6056	0.6080	0.6104	0.6128	0.6152	0.6176	0.6200	0.6224	58
32	0.6249	0.6273	0.6297	0.6322	0.6346	0.6371	0.6395	0.6420	0.6445	0.6469	57
33	0.6494	0.6519	0.6544	0.6569	0.6594	0.6619	0.6644	0.6669	0.6694	0.6720	56
34	0.6745	0.6771	0.6796	0.6822	0.6847	0.6873	0.6899	0.6924	0.6950	0.6976	55
35	0.7002	0.7028	0.7054	0.7080	0.7107	0.7133	0.7159	0.7186	0.7212	0.7239	54
36	0.7265	0.7292	0.7319	0.7346	0.7373	0.7400	0.7427	0.7454	0.7481	0.7508	53
37	0.7536	0.7563	0.7590	0.7618	0.7646	0.7673	0.7701	0.7729	0.7757	0.7785	52
38	0.7813	0.7841	0.7869	0.7898	0.7926	0.7954	0.7983	0.8012	0.8040	0.8069	51
39	0.8098	0.8127	0.8156	0.8185	0.8214	0.8243	0.8273	0.8302	0.8332	0.8361	50°
40°	0.8391	0.8421	0.8451	0.8481	0.8511	0.8541	0.8571	0.8601	0.8632	0.8662	49
41	0.8693	0.8724	0.8754	0.8785	0.8816	0.8847	0.8878	0.8910	0.8941	0.8972	48
42	0.9004	0.9036	0.9067	0.9099	0.9131	0.9163	0.9195	0.9228	0.9260	0.9293	47
43	0.9325	0.9358	0.9391	0.9424	0.9457	0.9490	0.9523	0.9556	0.9590	0.9623	46
44	0.9657	0.9691	0.9725	0.9759	0.9793	0.9827	0.9861	0.9896	0.9930	0.9965	45
	°1.0	°0.9	°0.8	°0.7	°0.6	°0.5	°0.4	°0.3	°0.2	°0.1	Deg.

NATURAL TANGENTS AND COTANGENTS.—*Concluded*

Deg.	°0.0	°0.1	°0.2	°0.3	°0.4	°0.5	°0.6	°0.7	°0.8	°0.9	
45	1.0000	1.0035	1.0070	1.0105	1.0141	1.0176	1.0212	1.0247	1.0283	1.0319	44
46	1.0355	1.0392	1.0428	1.0464	1.0501	1.0538	1.0575	1.0612	1.0649	1.0686	43
47	1.0724	1.0761	1.0799	1.0837	1.0875	1.0913	1.0951	1.0990	1.1028	1.1067	42
48	1.1106	1.1145	1.1184	1.1224	1.1263	1.1303	1.1343	1.1383	1.1423	1.1463	41
49	1.1504	1.1544	1.1585	1.1626	1.1667	1.1708	1.1750	1.1792	1.1833	1.1875	40°
50°	1.1918	1.1960	1.2002	1.2045	1.2088	1.2131	1.2174	1.2218	1.2261	1.2305	39
51	1.2349	1.2393	1.2437	1.2482	1.2527	1.2572	1.2617	1.2662	1.2708	1.2753	38
52	1.2799	1.2846	1.2892	1.2938	1.3985	1.3032	1.3079	1.3127	1.3175	1.3222	37
53	1.3270	1.3319	1.3367	1.3416	1.3465	1.3514	1.3564	1.3613	1.3663	1.3713	36
54	1.3764	1.3814	1.3865	1.3916	1.3968	1.4019	1.4071	1.4124	1.4176	1.4229	35
55	1.4281	1.4335	1.4388	1.4442	1.4496	1.4550	1.4605	1.4659	1.4715	1.4770	34
56	1.4826	1.4882	1.4938	1.4994	1.5051	1.5108	1.5166	1.5224	1.5282	1.5340	33
57	1.5399	1.5458	1.5517	1.5577	1.5637	1.5697	1.5757	1.5818	1.5880	1.5941	32
58	1.6003	1.6066	1.6128	1.6191	1.6255	1.6319	1.6383	1.6447	1.6512	1.6577	31
59	1.6643	1.6709	1.6775	1.6842	1.6909	1.6977	1.7045	1.7113	1.7182	1.7251	30°
60°	1.7321	1.7391	1.7461	1.7532	1.7603	1.7675	1.7747	1.7820	1.7893	1.7966	29
61	1.8040	1.8115	1.8190	1.8265	1.8341	1.8418	1.8495	1.8572	1.8650	1.8728	28
62	1.8807	1.8887	1.8967	1.9047	1.9128	1.9210	1.9292	1.9375	1.9458	1.9542	27
63	1.9626	1.9711	1.9797	1.9883	1.9970	2.0057	2.0145	2.0233	2.0323	2.0413	26
64	2.0503	2.4059	2.0686	2.0778	2.0872	2.0965	2.1060	2.1155	2.1251	2.1348	25
65	2.1445	2.1543	2.1642	2.1742	2.1842	2.1943	2.2045	2.2148	2.2251	2.2355	24
66	2.2460	2.2566	2.2673	2.2781	3.2889	2.2998	2.3109	2.3220	2.3332	2.3445	23
67	2.3559	2.3673	2.3789	2.3906	2.4023	2.4142	2.4262	2.4383	2.4504	2.4627	22
68	2.4751	2.4876	2.5002	2.5129	2.5257	2.5386	2.5517	2.5649	2.5782	2.5916	21
69	2.6051	2.6187	2.6325	2.6464	2.6605	2.6746	2.6889	2.7034	2.7179	2.7326	20°
70°	2.7475	2.7625	2.7776	2.7929	2.8083	2.8239	2.8397	2.8556	2.8716	2.8878	19
71	2.9042	2.9208	2.9375	2.9544	2.9714	2.9887	3.0061	3.0237	2.0415	3.0595	18
72	3.0777	3.0961	3.1146	3.1334	3.1524	2.1716	3.1910	3.2106	3.2305	3.2506	17
73	3.2709	3.2914	3.3122	3.3332	3.3544	3.3759	3.3977	3.4197	3.4420	3.4646	16
74	3.4874	3.5105	3.5339	3.5576	3.5816	3.6059	3.6305	3.6554	3.6806	3.7062	15
75	3.7321	3.7583	3.7848	3.8118	3.8391	3.8667	3.8947	3.9232	3.9520	3.9812	14
76	4.0108	4.0408	4.0713	4.1022	4.1335	4.1653	4.1976	4.2303	4.2635	4.2972	13
77	4.3315	4.3662	4.4015	4.4374	4.4737	4.5107	4.5483	4.5864	4.6252	4.6646	12
78	4.7046	4.7453	4.7867	4.8288	4.8716	4.9152	4.9594	5.0045	5.0504	5.0970	11
79	5.1446	5.1929	5.2422	5.2924	5.3435	5.3955	5.4486	5.5026	5.5578	5.6140	10°
80°	5.6713	5.7297	5.7894	5.8502	5.9124	5.9758	6.0405	6.1066	6.1742	6.2432	9
81	6.3138	6.3859	6.4596	6.5350	6.6122	6.6912	6.7720	6.8548	6.9395	7.0264	8
82	7.1154	7.2066	7.3002	7.3962	7.4947	7.5958	7.6996	7.8062	7.9158	8.0285	7
83	8.1443	8.2636	8.3863	8.5126	8.6427	8.7769	8.9152	9.0579	9.2052	9.3572	6
84	9.5144	9.677	9.845	10.02	10.20	10.39	10.58	10.78	10.99	11.20	5
85	11.43	11.66	11.91	12.16	12.43	12.71	13.00	13.30	13.62	13.95	4
86	14.30	14.67	15.06	15.46	15.89	16.35	16.83	17.34	17.89	18.46	3
87	19.08	19.74	20.45	21.20	22.02	22.90	23.86	24.90	26.03	27.27	2
88	28.64	30.14	31.82	33.69	35.80	38.19	40.92	44.07	47.74	52.08	1
89	57.29	63.66	71.62	81.85	95.49	114.6	143.2	191.0	286.5	573.0	0°
	°1.0	°0.9	°0.8	°0.7	°0.6	°0.5	°0.4	°0.3	°0.2	°0.1	Deg.

NOTE.—For cotangents use right-hand column of degrees and lower line of tenths.

ANALYTIC GEOMETRY

The Straight Line.—The equation of the straight line in its simplest form is $\frac{x}{a} + \frac{y}{b} = 1$, where a and b are the intercepts of the line on the axes of X and Y respectively.

The other useful equations of the straight line are: $y = mx + b$, where m is the tangent which the line makes with the axis of X. The equation of a line passing through a given point (x_1, y_1) is $y - y_1 = m(x - x_1)$ where m is entirely indeterminate, since any number of lines may pass through a point. The equation of a line passing through two points is

$$y - y_1 = \frac{y_2 - y_1}{x_2 - x_1}(x - x_1)$$

The distance between two points x_1, y_1 and x_2, y_2 is:

$$D = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

Distance from a point x_1, y_1 to a line $ax + by + c = 0$ is:

$$d = \frac{ax_1 + by_1 + c}{\sqrt{a^2 + b^2}}$$

The equation of an angle Φ between two lines $y = mx + b$ and $y = m'x + b'$ is:

$$\tan \Phi = \frac{m' - m}{1 + mm'}$$

The Circle.—The circle is the locus of all points in a plane equidistant from a given point.

The equation of a circle whose center lies at the origin is:

$$x^2 + y^2 = r^2.$$

If its center lies at (a, b):

$$(x - a)^2 + (y - b)^2 = r^2$$

If the origin lies on the left extremity of the diameter, the equation is:

$$(x - r)^2 + (y - 0)^2 = r^2 \text{ (as above)}$$

or simplifying

$$y^2 = 2rx - x^2$$

The Ellipse.—The ellipse is the locus of a point moving in a plane so that the sum of its distances from two points in the plane is a constant. The ratio of the constant sum (the major diameter) to the distance between the foci is known as the eccentricity, e.

The area of an ellipse $= \pi$ times the product of the semi-diameters.

The equation of the ellipse is

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \text{ (center at the origin)}$$

The tangent to the above ellipse through the point of tangency x_1, y_1 is

$$\frac{xx_1}{a^2} + \frac{yy_1}{b^2} = 1$$

The Parabola.—The parabola is the locus of a point moving in a plane so that its distance from a point (the focus) in the plane is always equal to its distance from a line (the directrix) in the plane. Its equation, the curve passing through the origin and its focus lying on the axis of X is $y^2 = 4px$, polar coördinates $\rho = p \sec^2 \frac{\theta}{2}$, where $4p$ is the double ordinate through the focus. A tangent to a parabola through the point of tangency x_1, y_1, is $yy_1 = p(x + x_1)$.

The tangent at any point makes equal angles with the axis and a line from the point of tangency to the focus. The parabola has no finite asymptotes.

The Hyperbola.—The hyperbola is the locus of a point moving in a plane so that the differences of its distances from two fixed points in the plane is a constant. Its equation, with its center at the origin and its foci on the axis of x is

$$\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1$$

Equilateral hyperbola: $x^2 - y^2 = a^2$.

Equilateral hyperbola referred to its axes as asymptotes: $xy = c^2$ (This is the isothermal curve of pressure and volume in gases).

Equation of the asymptotes

$$\frac{x}{a} = \frac{y}{b};\ \frac{x}{a} = -\frac{y}{b}$$

The tangent to a hyperbola bisects the angle formed by the two lines drawn from the point of tangency to the foci.

The Cycloid.—The cycloid is the curve generated by a point in the circumference of a circle rolling on a straight line. It consists of an infinite number of equal arches.

$$x = a \cos^{-1}\frac{a - y}{a} - \sqrt{2ay - y^2} \text{ or } \left.\begin{aligned} x &= a(\theta - \sin \theta) \\ y &= a(1 - \cos \theta) \end{aligned}\right\}$$

The Epicycloid and Hypocycloid.—The epicycloid is generated by a point in the circumference of a circle rolling upon another circle. The hypocycloid is the curve generated by a point on the circumference of a circle rolling inside another circle.

$$\textbf{Epicycloid} \begin{cases} x = (a + b) \cos \theta - b \cos \dfrac{a + b}{b}\,\theta \\[2ex] y = (a + b) \sin \theta - b \sin \dfrac{a + b}{b}\,\theta \end{cases}$$

$$\textbf{Hypocycloid} \begin{cases} x = (a - b) \cos \theta + b \cos \dfrac{a - b}{b}\,\theta \\[2ex] y = (a - b) \sin \theta - b \sin \dfrac{a - b}{b}\,\theta \end{cases}$$

where a is the radius of the main circle, and b of the generating circle.

Cubical Parabola.—Formula, $a^2y = x^3$.

Semicubical Parabola.—Formula, $ay^2 = x^3$.

Witch of Agnesi.—Formula, $y = \dfrac{8a^3}{x^2 + 4a^2}$.

Cissoid of Diocles.—Formula, $y^2 = \dfrac{x^3}{2a - x}$

$$\rho = 2a \tan \theta \sin \theta.$$

This and the conchoid were invented to solve the problems of the duplication of the cube, *i.e.*, given a cube, a^3, whose side is a, to construct the side of a cube, $2a^3$.

Lemniscate of Bernouilli.—Formula, $(x^2 + y^2)^2 = a^2(x^2 - y^2)$

$$\rho^2 = a^2 \cos \theta.$$

This and the following have a singular point at 0, 0.

Strophoid.—Formula, $y^2 = x^2\left(\dfrac{a - x}{a + x}\right)$

$$\rho = a(\cos \theta - \sin \theta \tan \theta).$$

Cardioid.—Formula, $x^2 + y^2 + ax = a\sqrt{x^2 + y^2}$

$$\begin{cases} x = a \cos \theta \, (1 - \cos \theta) \\ y = a \sin \theta \, (1 - \cos \theta) \end{cases}$$

$$\rho = a(1 - \cos \theta)$$

This is a special case of the epicycloid in which the generating circles are equal.

The Probability Curve.—Formula, $y = e^{-x^2}$.

The Caternary.—The caternary is the curve assumed by a uniform, completely flexible cord supported at its two ends. Its equation is

$$y = \frac{a}{2}\left(e^{\frac{x}{a}} + e^{-\frac{x}{a}}\right)$$

where e is the base of the Napierian system of logarithms.

The Involute.—The involute is the curve described by a point in a string which is being kept taut and unwound from a cylinder.

$$\begin{cases} x = a(\cos \theta + \theta \sin \theta) \\ y = a(\sin \theta + \theta \cos \theta) \end{cases}$$

or

$$\theta = \frac{\sqrt{\rho^2 - a^2}}{a} - \tan^{-1}\frac{\sqrt{\rho^2 - a^2}}{a}$$

The Spiral of Archimedes is a curve described by the extremity of a radius vector which lengthens in proportion to the angle traversed. That is, the turns are equidistant from each other.

$$\rho = a\theta$$

Hyperbolic Spiral.—Formula, $\rho\theta = a$.

Logarithmic Spiral.—Formula, $\rho = e^{a\theta}$.

Lituus.—Formula, $\rho^2\theta = a^2$.

CALCULUS

Elementary Differentials

$d(c) = 0$

$d(x) = 1$

$d(cu) = cdu$

$d(cx) = c$

$$d(u \pm v \pm w\ .\ .\ .\ ) = du \pm dv \pm dw\ .\ .\ .$$
$$d(uv) = vdu + udv$$
$$d(uvw) = vwdu + uwdv + uvdw$$
$$\frac{d(uvw)}{uvw} = \frac{du}{u} + \frac{dv}{v} + \frac{dw}{w}$$
$$d(u^n) = nu^{n-1}du;\ d(x^n) = nx^{n-1}$$
$$d\ \frac{u}{v} = \frac{vdu - udv}{v^2};\ d\left(\frac{1}{v}\right) = \frac{dv}{v^2};\ d\left(\frac{1}{x}\right) = -\frac{1}{x^2}$$

$$d(\sin\ x) = \cos x \qquad d(\tan\ x) = \sec^2 x$$
$$d(\sec\ x) = \sec x \tan x \qquad d(\cos\ x) = -\sin x$$
$$d(\cot\ x) = -\csc^2 x \qquad d(\csc\ x) = -\csc x \cot x$$
$$d \sin^{-1}u = \frac{du}{\sqrt{1-u^2}} \qquad d \tan^{-1} u = \frac{du}{1+u^2}$$
$$d \sec^{-1}u = \frac{du}{u\sqrt{u^2-1}} \qquad d \cos^{-1} u = -\frac{du}{\sqrt{1-u^2}}$$
$$d \cot^{-1}u = -\frac{du}{1+u^2} \qquad d \csc^{-1} u = -\frac{du}{u\sqrt{u^2-1}}$$
$$d \log_a u = \log_a e \cdot \frac{du}{u};\ d \log_a x = \log_a e = \frac{1}{x}$$
$$d \log_e u = \frac{du}{u}$$
$$da^u = a^u \log_e a du$$
$$de^u = e^u du$$

Fundamental Integrals[1]

$$\int adx = ax$$
$$\int af(x)dx = a\int f(x)dx$$
$$\int \frac{dx}{x} = \log x$$
$$\int x^m dx = \frac{x^{m+1}}{m+1}, \text{ when } m \text{ is different from } -1$$
$$\int e^x dx = e^x$$
$$\int a^x \log adx = a^x$$
$$\int \frac{dx}{1+x^2} = \tan^{-1} x$$
$$\int \frac{dx}{\sqrt{1-x^2}} = \sin^{-1} x$$
$$\int \frac{dx}{x\sqrt{x^2-1}} = \sec^{-1} x$$
$$\int \frac{dx}{\sqrt{2x-x^2}} = \text{vers}^{-1} x$$

[1] For the more complicated integrals, see B. O. PIERCES' "Short Table of Integrals" and the various works on integral calculus.

$\int \cos x dx = \sin x$
$\int \sin x dx = -\cos x$
$\int \cot x dx = \log \sin x$
$\int \tan x dx = -\log \sin x$
$\int \tan x \sec x dx = \sec x$
$\int \sec^2 x dx = \tan x$
$\int \csc^2 x dx = -\cot x$
$\int [f(x) + \varphi(x) + \psi(x)]dx = \int f(x)dx + \int \varphi(x)dx + \int \psi(x)dx$
$\int udv = uv - \int vdu$ where u and v are functions of x

$$\int u \frac{dv}{dx} dx = uv - \int v \frac{du}{dx} dx$$

SECTION II

METALLURGICAL PRICE AND PRODUCTION STATISTICS

Metal Prices

For the current figures on metal prices it is, of course, necessary to refer to the "Engineering and Mining Journal." But it is often convenient to have the figures for some years back, for instance in computing mine valuations, or in calculations on metallurgical processes where the value of a metal over a term of years enters into the problem. For that reason I have introduced the following tables.

Monthly Prices of Electrolytic Copper at New York for the Last 10 Years
(In Cents per Pound)

	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914
Jan.	15.008	18.310	24.404	13.726	13.893	13.620	12.295	14.094	16.488	14.223
Feb.	15.011	17.869	24.869	12.905	12.949	13.332	12.256	14.084	14.971	14.491
March	15.125	18.361	25.065	12.704	12.387	13.255	12.139	14.698	14.713	14.131
April	14.920	18.375	24.224	12.743	12.562	12.733	12.019	15.741	15.291	14.211
May	14.627	18.457	24.048	12.598	12.893	12.550	11.989	16.031	15.436	13.996
June	14.673	18.442	21.665	12.675	13.214	12.404	12.385	17.234	14.672	13.603
July	14.888	18.190	22.130	12.702	12.880	12.215	12.463	17.190	14.190	13.223
Aug.	15.664	18.380	18.356	13.462	13.007	12.490	12.405	17.498	15.400	[1]
Sept.	15.965	19.033	15.565	13.388	12.870	12.379	12.201	17.508	16.328	[1]
Oct.	16.279	21.203	13.169	13.354	12.700	12.553	12.189	17.314	16.337	[1]
Nov.	16.599	21.833	13.391	14.130	13.125	12.742	12.616	17.326	15.182	11.739
Dec.	18.328	22.885	13.163	14.111	13.298	12.581	13.552	17.376	14.224	12.801
Year's average	15.590	19.278	20.004	13.208	12.982	12.738	12.376	16.341	15.269	......

These figures from the *Engineering and Mining Journal.*

[1] No quotations.

Average Monthly Prices of Copper Manufactures

(In Cents per Pound)

	1911		1912		1913		1914	
	Copper wire	Sheet copper	Copper wire	Sheet copper	Copper wire	Sheet copper	Copper wire	Sheet copper
Jan.	14.06	18.50	15.75	19.50	19.09	23.50	15.94	20.75
Feb.	13.50	18.50	15.25	19.50	16.38	22.50	15.88	20.50
March	13.25	18.50	16.03	20.30	16.39	21.50	15.60	20.35
April	13.75	18.50	17.06	21.50	16.50	21.50	15.25	20.25
May	13.75	18.50	17.30	21.63	16.50	21.50	15.23	19.90
June	13.75	18.50	18.68	22.50	16.18	21.10	15.03	19.56
July	13.90	18.50	19.13	22.50	15.88	20.50	14.88	19.38
Aug	13.81	18.50	19.13	22.75	16.60	21.50	14.63	18.80
Sept	13.75	18.50	19.13	23.50	17.84	22.50	14.34	18.00
Oct.	13.50	18.50	19.13	23.50	17.75	22.50	13.34	17.38
Nov	13.75	18.63	19.13	23.50	17.28	21.15	12.50	17.50
Dec.	14.94	19.13	19.13	23.50	15.79	20.50	14.25	18.88
Year	13.81	18.56	17.96	22.02	16.85	21.69	14.74	19.24

Monthly Prices of Lead at New York for the Last 10 Years

(In Cents per Pound)

	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914
Jan.	4.552	5.600	6.000	3.691	4.175	4.700	4.483	4.435	4.321	4.111
Feb.	4.450	5.464	6.000	3.725	4.018	4.613	4.440	4.026	4.325	4.048
March	4.470	5.350	6.000	3.838	3.986	4.459	4.394	4.073	4.327	3.970
April	4.500	5.404	6.000	3.993	4.168	4.376	4.412	4.200	4.381	3.810
May	4.500	5.685	6.000	4.253	4.287	4.315	4.373	4.194	4.342	3.900
June	4.500	5.750	5.760	4.466	4.350	4.343	4.435	4.392	4.325	3.900
July	4.524	5.750	5.288	4.447	4.321	4.404	4.499	4.720	4.353	3.891
Aug	4.665	5.750	5.250	4.580	4.363	4.400	4.500	4.569	4.624	3.875
Sept	4.850	5.750	4.813	4.515	4.342	4.400	4.485	5.048	4.698	3.828
Oct.	4.850	5.750	4.750	4.351	4.341	4.400	4.265	5.071	4.402	3.528
Nov.	5.200	5.750	4.376	4.330	4.370	4.442	4.298	4.615	4.293	3.683
Dec.	5.422	5.900	3.658	4.213	4.560	4.500	4.450	4.303	4.047	3.800
Year's average	4.707	5.347	5.325	4.200	4.273	4.446	4.420	4.471	4.370	3.862

These figures from the *Engineering and Mining Journal.*

Monthly Prices of Silver at New York for the Last 10 Years

(In Cents per Fine Ounce)

	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914
Jan.	60.690	65.288	68.673	55.678	51.750	52.375	53.795	56.260	62.938	57.572
Feb.	61.023	66.108	68.835	56.000	51.472	51.534	52.222	59.043	61.642	57.506
March.	58.046	64.597	67.519	55.365	50.468	51.454	52.745	58.375	57.870	58.067
April.	56.600	64.765	65.462	54.505	51.428	53.221	53.325	59.207	59.490	58.519
May.	57.832	66.976	65.971	52.795	52.905	53.870	53.308	60.880	60.361	58.175
June.	58.428	65.394	67.090	53.663	52.538	53.462	53.043	61.290	58.990	56.471
July.	58.915	65.105	68.144	53.115	51.043	54.150	52.630	60.654	58.721	54.678
Aug.	60.259	65.949	68.745	51.683	51.125	52.912	52.171	61.606	59.293	54.344
Sept.	61.695	67.927	67.792	51.720	51.440	53.295	52.440	63.078	60.640	53.290
Oct.	62.034	69.523	62.435	51.431	50.923	55.490	53.340	63.471	60.793	50.654
Nov.	63.849	70.813	58.677	49.647	50.703	55.635	55.719	62.792	58.995	49.082
Dec.	64.850	69.050	54.565	48.769	52.226	54.428	54.905	63.365	57.760	49.375
Year's average.	60.352	66.791	65.327	52.864	51.502	53.486	53.304	60.835	59.791	54.811

Note.—Silver in New York is sold by the fine ounce, 999, in London by the standard ounce, 925 fine.

Average Prices of Aluminum, Quicksilver, Antimony and Platinum for the Last 10 Years

	Aluminum, cents per pound	Quicksilver, dollars per flask (flask = 75 lb.)		Antimony, cents per pound			Platinum, dollars per ounce
	No. 1	San Francisco	N. Y.	Cookson's	Halletts'	Ordinaries	
1905	....	38.00	38.50	....	....	....	....
1906	35.75	39.46	40.90	22.78	21.94	21.73	28.04
1907	41.51	39.60	41.50	16.97	15.53	14.84	26.18
1908	31.00	44.17	44.84	8.70	8.42	8.00	22.62
1909	22.40	45.45	46.30	8.30	8.02	7.47	24.87
1910	22.85	46.51	47.06	8.25	7.88	7.39	32.70
1911	20.07	46.01	46.54	8.59	8.16	7.54	43.12
1912	22.01	42.05	42.49	8.90	8.26	7.76	45.55
1913	23.64	39.28	39.54	8.73	8.22	7.52	44.88
1914	18.63	48.68	48.31	10.732	....	8.76	45.14

These figures from the *Engineering and Mining Journal*.

Monthly Prices of Spelter at St. Louis for the Last 10 Years
(In Cents per Pound)

	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914
Jan........	6.032	6.337	6.582	4.363	4.991	5.951	5.302	6.292	6.854	5.112
Feb........	5.989	5.924	6.664	4.638	4.739	5.419	5.368	6.349	6.089	5.228
Mar........	5.917	6.056	6.687	4.527	4.607	5.487	5.413	6.476	5.926	5.100
Apr........	5.667	5.931	6.535	4.495	4.815	5.289	5.249	6.483	5.491	4.963
May........	5.284	5.846	6.291	4.458	4.974	5.041	5.198	6.529	5.256	4.924
June........	5.040	5.948	6.269	4.393	5.252	4.978	5.370	6.727	4.974	4.850
July........	5.247	5.856	5.922	4.338	5.252	5.002	5.545	6.966	5.128	4.770
Aug........	5.556	5.878	5.551	4.556	5.579	5.129	5.803	6.878	5.508	5.418
Sept........	5.737	6.056	5.086	4.619	5.646	5.364	5.719	7.313	5.444	5.230
Oct........	5.934	6.070	5.280	4.651	6.043	5.478	5.951	7.276	5.188	4.750
Nov........	5.984	6.225	4.775	4.909	6.231	5.826	6.223	7.221	5.083	4.962
Dec........	6.374	6.443	4.104	4.987	6.099	5.474	6.151	7.081	5.004	5.430
Year's average........	5.730	6.048	5.812	4.578	5.352	5.370	5.608	6.799	5.504	5.061

Monthly Prices of Tin at New York for the Last 10 Years

	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914
Jan........	29.325	36.390	41.548	27.380	28.060	32.700	41.255	42.529	50.298	37.779
Feb........	29.262	36.403	42.102	28.978	28.290	32.920	41.614	42.962	48.766	39.830
Mar........	29.523	36.662	41.313	30.577	28.727	32.403	40.157	42.577	46.832	38.038
Apr........	30.525	38.900	40.938	31.702	29.445	32.976	42.185	43.923	49.115	36.154
May........	30.049	43.313	42.149	30.015	29.225	33.125	43.115	46.053	49.038	33.360
June........	30.329	39.260	42.120	28.024	29.322	32.769	44.605	45.815	44.820	30.577
July........	31.760	37.275	41.091	29.207	29.125	32.695	42.406	44.519	40.260	31.707
Aug........	32.866	40.606	37.667	29.942	29.966	33.972	43.319	45.857	41.582	......
Sept........	32.095	40.516	36.689	28.815	30.293	34.982	39.755	49.135	42.410	32.675
Oct........	32.481	42.852	32.620	29.444	30.475	36.190	41.185	50.077	40.462	30.284
Nov........	33.443	42.906	30.833	30.348	30.869	36.547	43.125	49.891	39.810	33.304
Dec........	35.835	42.750	27.925	29.144	32.913	38.199	44.655	49.815	37.635	33.601
Year s average.......	31.358	39.819	38.160	29.465	29.725	34.123	42.281	46.096	44.252	......

These figures from the *Engineering and Mining Journal.*

Metal Production Figures

For the latest production figures the reader is referred to the annual statistical number of the *Engineering and Mining Journal* and to the "Mineral Industry." However, despite the fact that the following figures are somewhat out of date they are offered as useful guides.

Production of Metals in the United States[1]

Metal	Unit	1912	1913	1914
Aluminum	Pounds	(g)32,990,000	(g)49,601,500	(h)45,000,000
Copper (a)	Pounds	1,241,762,508	1,225,735,834	1,158,581,876
Ferromanganese	Long tons	227,725	229,834	185,118
Gold (b)	Dollars	93,451,500	88,884,400	94,531,800
Iron	Long tons	29,499,422	30,736,477	23,147,226
Lead (c)	Short tons	410,006	433,476	538,735
Nickel (e)	Pounds	42,168,769	47,124,330	(e)30,067,064
Quicksilver	Flasks	(f)25,147	(h)20,000	16,300
Silver (b)	Troy ounces	63,766,800	66,801,500	72,455,100
Zinc (d)	Short tons	348,638	358,262	362,361

(a) Production from ore originating in the United States. (b) The statistics for 1912 and 1913 are the final and those for 1914 are the preliminary statistics reported jointly by the directors of the Mint and the U. S. Geological Survey. (c) Production of refined lead ore and scrap originating in the United States: antimonial lead is included. (d) Total production of smelters, except those treating dross and junk exclusively; includes spelter derived from imported ore. (e) Imports; for 1914, first 10 months only. This nickel is refined in the United States for the production of metal, oxide and salts. (f) As reported by U. S. Geological Survey. (g) As reported by the Metallgesellschaft, Frankfurt am Main. (h) Estimated.

Production of Mineral and Chemical Substances

Substance	Unit	1912	1913	1914
Arsenic	Pounds	5,852,000	4,624,140	8,651,940
Coal, anth.(a)	Short tons	84,478,527	91,626.825	90,821,507
Coal, bitu.(a)	Short tons	449,964,723	478,688,867	422,703,970
Coke(a)	Short tons	42,528,653	45,953,808	34,555,914
Copper sulphate	Long tons	39,480,741	54,330,000	31,776,670
Iron ores	Long tons	59,196,778	61,847,116	42,911,897

(a) The coal and coke statistics are the estimates of Coal Age.

World's Production of Nickel
(As reported by Metallgesellschaft, Frankfurt a. M., in Metric Tons)

	1910	1911	1912
United States and Canada	10,000	12,000	15,000
England	3,500	4,500	5,200
Germany	4,500	5,000	5,000
France	1,500	2,000	2,100
Others	600	1,000	1,200
Totals	20,000	24,500	28,500

[1] As tabulated in the *Engineering and Mining Journal*, Jan. 9, 1915.

World's Production of Quicksilver

(In Metric Tons)
(From statistical report of the Metallgesellschaft, Frankfurt am Main)

	1911	1912	1913
United States:			
a. California (*a*)	578	701	578
b. Texas	116	154	136
c. Other states	37		
United States	731	855	714
Spain (*b*)	1486	1490	1490
Austria-Hungary	793	783	855
Italy	931	986	988
Mexico (estimated)	150	150	150
Total	4100	4300	4200

(*a*) *Eng. and Min. Journ.* (*b*) Exports.

World's Consumption of Aluminum

(In Metric Tons)
(From statistical report of the Metallgesellschaft, Frankfurt am Main)

	1911	1912	1913
United States (*a*)	20,900	29,800	32,800
France	5,000	6,000	7,000
England	3,000	4,000	5,000
Italy	900	1,000	1,000
Other countries	17,000	22,100	21,000
Totals	46,800	62,900	66,800

(*a*) U. S. Geological Survey.

World's Production of Aluminum

(In Metric Tons)
(From statistical report of the Metallgesellschaft, Frankfurt am Main)

	1911	1912	1913
United States	18,000	19,500	22,500
Canada (exports)	2,300	8,300	5,900
Germany, Austria-Hungary, Switzerland	8,000	12,000	12,000
France	10,000	13,000	18,000
England	5,000	7,500	7,500
Italy	800	800	800
Norway	900	1,500	1,500
Totals	45,000	62,600	68,200

World's Production of Pig Lead

(In Metric Tons)
(From statistical report of the Metallgesellschaft, Frankfurt am Main)

	1911	1912	1913
Spain (*a*)	175,100	186,700	203,000
Germany	164,400	176,600	181,100
France	23,600	31,100	(*c*)28,000
Great Britain	26,000	29,200	30,500
Belgium	44,300	51,200	50,800
Italy	16,700	21,500	21,700
Austria-Hungary	19,600	21,400	24,100
Greece	14,300	14,500	18,400
Sweden and Norway	1,100	1,300	1,500
Russia	1,000	(*c*)1,000	(*c*)1,000
Asiatic Turkey	12,400	12,500	13,900
Total Europe (*b*)	498,500	547,000	574,000
United States	377,900	387,300	407,800
Mexico	124,600	(*c*)108,000	(*c*)62,000
Canada	10,700	16,300	17,100
Total North America	513,200	511,600	486,900
Japan	4,200	3,600	(*c*)3,600
Australia	99,600	107,400	116,000
Other countries	20,500	12,200	6,200
Total world's production	1,136,000	1,181,800	1,186,700

(*a*) Exports. (*b*) Including Asiatic Turkey. (*c*) Estimated.

Production of Lead (Refinery Statistics)[1] (*a*)

(In Tons of 2000 Lb.)

Class	1911	1912	1913	1914
Domestic				
Desilverized	211,041	236,207	261,616	318,697
Antimonial	8,916	9,239	16,345	17,177
S. E. Missouri	155,008	145,366	133,203	177,413
S. W. Missouri	25,993	19,224	22,312	25,448
Totals	400,958	410,036	433,476	538,735
Foreign:				
Desilverized	89,487	82,715	54,774	28,475
Antimonial	4,929	5,003	2,300	1,119
Totals	94,416	87,718	57,074	29,594
Grand totals	495,374	497,754	490,550	568,329

[1] As reported by the *Engineering and Mining Journal.*
(*a*) These figures include the lead derived from scrap and junk by primary smelters.

World's Consumption of Lead

(In Metric Tons)

(From statistical report of the Metallgesellschaft, Frankfurt am Main)

	1911	1912	1913
Germany	232,900	232,100	223,500
Great Britain	198,300	196,300	191,400
France	99,600	104,700	107,600
Russia	42,900	45,600	58,800
Belgium	43,000	44,900	42,900
Italy	36,300	33,000	32,600
Austria-Hungary	36,200	37,800	35,500
Holland (*a*)	6,800	6,300	9,500
Switzerland	5,000	6,400	5,800
Other European countries	3,500	4,400	6,300
Total Europe	704,500	711,500	713,900
United States	364,400	398,400	401,300
Canada	21,100	30,000	22,900
Japan	18,900	21,800	(*a*)18,500
Australia	9,100	10,100	9,600
Other countries	31,200	30,000	(*a*)30,000
Total world's consumption	1,149,200	1,201,800	1,196,200

(*a*) Estimated.

World's Production of Spelter

(In Metric Tons)

(From statistical report of the Metallgesellschaft, Frankfurt am Main)

	1911	1912	1913
Germany			
Rheinland-Westphalia	81,458	86,619	92,852
Silesia	156,174	169,088	170,119
Other districts	12,761	15,357	20,142
Belgium	195,092	200,198	197,703
Holland	22,733	23,932	24,323
Great Britain	66,956	57,231	59,146
France and Spain	64,221	72,161	71,023
Austria and Italy	16,876	19,604	21,707
Russia	9,936	8,763	7,610
Norway	6,680	8,128	9,287
Sweden	....	....	....
Europe	632,887	661,081	673,912
United States	267,472	314,512	320,283
Australia	1,727	2,296	3,724
Total	902,100	977,900	997,900

World's Consumption of Spelter
(In Metric Tons)
n statistical report of the Metallgesellschaft, Frankfurt am Main)

	1911	1912	1913
d States	251,600	312,900	313,300
any	219,300	225,800	232,000
Britain	175,700	185,200	194,600
e	82,000	82,000	81,100
m	73,700	77,200	76,400
a-Hungary	43,500	46,800	40,400
[illegible]	28,900	27,900	33,300
[illegible]	10,100	10,700	10,900
[illegible]	4,800	4,700	5,900
d (estimated)	4,000	4,000	4,000
countries (estimated)	17,800	19,700	20,900
al	911,400	996,900	1,012,700

Zinc Smelting Capacity of the United States[1]
(Number of Retorts at End of Years)

Name	Situation	1913	1914
Zinc Smelting Co.	Altoona, Kan.	3,300	(b) 3,840
n Zinc & Chem. Co.	Langeloth, Penn.	....	864
n Zinc Co. of Ill.	Hillsboro, Ill.	3,200	4,000
n Zinc, Lead & Smg. Co.	Dearing, Kan.	3,840	(a) 3,840
n Zinc, Lead & Smg. Co.	Caney, Kan.	3,648	(b) 3,648
ille Zinc Co.	Bartlesville, Okla.	5,184	5,184
ille Zinc Co.	Collinsville, Okla.	8,064	8,064
e Zinc Co.	Chanute, Kan.	(b) 1,280	(a) 1,280
urg Zinc Co.	Clarksburg, W. Va.	2,712	(d) 2,712
ille Zinc Co.	Collinsville, Ill.	(b) 1,536	(a) 1,536
inc Co.	St. Louis, Mo.	2,000	1,100
inc Co.	Cherryvale, Kan.	4,800	4,800
Mining & Smg. Co.	Neodesha, Kan.	3,760	3,840
Mining & Smg. Co.	E. St. Louis, Ill.	....	3,240
i Chemical Co.	Clarksburg, W. Va.	5,760	5,760
i Chemical Co.	Meadowbrook, W. Va.	6,912	6,912
Zinc Co.	Danville, Ill.	1,800	(d) 1,800
Zinc Co.	Peru, Ill.	4,640	(d) 4,640
pe Spelter Co.	La Harpe, Kan.	1,856	(d) 1,856
Lanyon Zinc & Acid Co.	Hillsboro, Ill.	1,600	1,840
-Starr Sm. Co.	Bartlesville, Okla.	3,456	3,456
ssen & Hegeler Zinc Co.	La Salle, Ill.	5,256	5,256
Point Zinc Co.	Depue, Ill.	6,800	9,[illegible]
d Zinc Co.	Bartlesville, Okla.	4,480	[illegible]
d Zinc Co.	Springfield, Ill.	3,200	[illegible]
Zinc Co.	Nevada, Mo.	(a) 648	
rsey Zinc Co.	Palmerton, Penn.	5,7[illegible]	
rg Zinc Co.	Pittsburg, Kan.	(b) [illegible]	
Vestern Spelter Co.	Gas City, Kan.	4,[illegible]	
al Zinc Co.	Sandoval, Ill.	[illegible]	
uel & Manufacturing Co.	Collinsville, Okla.	[illegible]	
pelter Co.	Sand Springs, Okla.	..	
States Zinc Co.	Pueblo, Colo.		
	Totals..........		

eported by the *Engineering and Mining Jour*
active throughout year. (*b*) Inactive du
t being dismantled. (*d*) No report rece
r.

Production of Zinc[1]

(In Tons of 2000 Lb.)
(By Ore Smelters (*a*))

States	1911	1912	1913	1914
Colorado	7,477	8,860	8,637	8,152
Illinois	88,681	94,902	111,551	130,587
Missouri and Kansas	106,173	111,761	85,157	53,424
Oklahoma	46,333	76,837	83,230	92,467
East	47,172	56,278	69,687	77,731
Totals	295,836	348,638	358,262	362,361

(*a*) Includes some works that smelt dross and scrap as well as ore, but does not include works that smelt dross and scrap only. Discrepancies among statistical reports of the spelter production of the United States arise largely on account of the difference in the dividing line that is drawn in this respect.

Silver-lead Smelting Works of North America[1]

Company	Place	Furnaces	Annual capacity (*a*)
American Smelting & Refining Co.	Denver	7	511,000
American Smelting & Refining Co.	Pueblo	7	380,000
American Smelting & Refining Co.	Durango	4	146,000
American Smelting & Refining Co.	Leadville	10	509,000
American Smelting & Refining Co.	Murray	8	657,000
American Smelting & Refining Co.	East Helena	4	306,600
American Smelting & Refining Co.	Omaha (*c*)	2	82,000
American Smelting & Refining Co.	Chicago (*c*)	2	60,000
American Smelting & Refining Co.	Perth Amboy (*c*)	3	140,000
American Smelting & Refining Co.	El Paso	7	380,000
Selby Smelting & Lead Co.	Selby	3	210,000
Ohio & Colorado Smelting Co.	Salida, Colo.	4	345,000
U. S. Smelting Co.	Midvale, Utah	6	500,000
Needles Smelting Co.	Needles, Cal. (*d*)	2	70,000
Pennsylvania Smelting Co.	Carnegie, Pa.	2	60,000
International Smelting Co.	Tooele, Utah	5	500,000
Totals, United States		76	4,856,600
American Smelting & Refining Co.	Monterey	10	475,000
American Smelting & Refining Co.	Aguascalientes	2	100,000
American Smelting & Refining Co.	Chihuahua	5	274,000
American Smelters Securities Co.	Velardeña	3	140,000
Compania Metalurgica Mexicana	San Luis Potosi	11	385,000
Compania Metalurgica de Torreon	Torreon	8	360,000
Compania Minera de Peñoles	Mapimi (*d*)	6	325,000
Totals, Mexico		45	2,059,000
Consolidated Mining & Smelting Co.	Trail, B. C.	3	110,000

(*a*) Tons of charge. (*c*) Smelt chiefly refinery between-products. (*d*) Not operated in 1914.

[1] *Engineering and Mining Journal*, Jan. 10, 1914.

World's Consumption of Copper
(In Metric Tons)
(From statistical report of the Metallgesellschaft, Frankfurt am Main)

Europe	1911	1912	1913
Germany	222,500	231,700	259,300
Great Britain	159,100	144,700	140,300
France	95,700	98,500	103,600
Austria-Hungary	38,500	48,200	39,200
Russia	32,800	40,000	40,200
Italy	29,400	34,200	31,200
Belgium	13,500	15,000	15,000
Netherlands	1,000	1,000	1,000
Other European countries	10,000	10,200	(a)13,300
Total consumption in Europe	602,500	623,500	643,100
America			
United States	321,900	371,800	348,100
Others in America	3,000	3,000	3,000
Total consumption in America	324,900	374,800	351,100
Asia, Australia, Africa			
Production Japan and Australia	95,000	111,900	119,000
Imports from Europe	500	1,400	1,000
Imports from America	....	500	80
Total	95,500	113,800	120,100
Exports to Europe and America	68,800	73,400	69,800
Consumption in Asia, Australia and Africa	26,700	40,400	50,300
World's consumption	954,100	1,038,700	1,044,500
World's production	893,800	1,018,600	1,005,900

(a) Estimated.

World's Production of Copper (a)
(In Metric Tons)

Country	1911	1912	1913	1914
United States	491,634	563,260	555,990	525,529
Mexico	61,884	73,617	58,323	36,337
Canada	25,570	34,213	34,880	34,027
Cuba	3,753	4,393	3,381	6,251
Australasia	(b)42,510	(b)47,772	(b)47,325	(b)37,592
Peru	28,500	26,483	25,487	23,647
Chile	33,088	39,204	39,434	40,876
Bolivia	2,950	4,681	(b) 3,658	(b)1,306
Japan	(d)52,303	(d)62,486	(b)73,152	(d)72,938
Russia	(c)25,747	(c)33,550	(c)34,316	(b)31,938
Germany	(b)22,363	(b)24,303	(b)25,308	(b)39,480
Africa	(b)17,252	(b)16,632	(b)22,870	(b)24,135
Spain and Portugal	(b)52,878	(b)59,873	(b)54,696	(b)37,099
Other countries	(b)26,423	(b)29,555	(b)27,158	(b)25,176
Totals	886,855	1,020,022	1,005,978	923,888

(a) The statistics in this table are "E. & M. J." compilations, except where specially noted to the contrary. (b) As reported by Henry R. Merton & Co. (c) As officially reported. (d) Privately communicated from Japan. (e) Exports as reported by Henry R. Merton & Co. (h) Estimated. (i) Communicated through London.

Smelters' Production of Copper in the United States[1]
(In Pounds)

State	1911	1912	1913	1914
Alaska	19,412,000	32,602,000	24,452,000	24,288,000
Arizona	300,578,816	357,952,962	399,849,745	387,978,852
California	36,806,762	31,069,029	32,390,272	29,515,488
Colorado	8,474,848	7,502,000	7,670,090	10,104,579
Idaho	3,745,210	5,964,542	8,434,028	4,856,460
Michigan	216,412,867	231,628,486	159,437,262	157,089,795
Montana	271,963,769	309,247,735	285,336,153	243,139,737
Nevada	65,385,728	82,530,608	84,683,961	60,078,095
New Mexico	1,518,288	27,488,912	46,953,414	64,338,892
Utah	138,336,905	131,673,803	147,591,955	153,555,902
Washington	....	1,121,109	448,805	165,023
East and South	19,656,971	18,592,655	24,333,014	19,213,965
Other States	1,564,207	4,396,667	4,155,135	4,257,088
Totals	1,083,856,371	1,241,762,508	1,225,735,834	1,158,581,876

[1] As reported by the *Engineering and Mining Journal*.

(a) Includes copper originating in states other than those enumerated and also copper whose origin could not be correctly distributed at this early date. Indeed, the distribution for 1914 in several cases in this table must be regarded as merely provisional. Thus, Utah is undoubtedly credited with more or less copper that belongs to Idaho and Nevada.

(SMELTERS' PRODUCTION—*Continued*)
(In Pounds)

urce	1911	1912	1913	1914
nerican	1,284,932,019	1,489,168,562	1,438,565,881	1,327,488,479
n ore..	34,392,091	53,701,307	55,803,202	50,101,308
....	18,529,547	11,949,348	22,427,889	20,894,559
als.....	1,337,853,657	1,554,719,217	1,516,796,972	1,398,484,346
eign re- s......	32,413,440	45,735,673	36,682,605	36,765,920
nerican ers	1,305,440,217	1,508,983,544	1,480,114,367	1,361,718,426
copper orted...	146,422,851	144,480,144	169,315,869	131,125,076
crude er.....	1,451,863,068	1,653,463,688	1,649,430,236	1,492,843,502

WORLD'S PRODUCTION OF SILVER
Smelters' Production—In Metric Tons
om statistical report of the Metallgesellschaft, Frankfurt am Main)

	1911	1912	1913
t Britain	536.1	499.3	395.1
any	420.0	476.0	537.9
um	264.7	252.7	280.0
n and Portugal	134.9	117.6	(*a*)130.0
ce	53.0	47.0	(*a*)47.0
ria-Hungary	63.1	61.2	58.9
	14.2	12.1	14.4
ray	7.2	7.6	(*a*)8.0
ia	4.9	(*a*)5.0	(*a*)5.0
ey (*a*)	1.5	1.5	1.5
en	....	1.2	0.9
tal Europe	1499.6	1481.2	1478.7
ed States	3891.9	4073.0	4059.1
co	1055.6	*b*1063.2	*b*1159.2
ral and South America (*a*)	200.0	200.0	200.0
da	509.2	593.4	546.5
tal America	5656.7	5929.6	5974.8
ia (Japan)	141.6	138.1	148.9
stralia	129.1	136.4	143.0
l production	7427.0	7685.3	7745.4

Estimated. (*b*) Fiscal years 1910–1911 and 1911–1912.

Silver Production in the United States
(In Fine Ounces)

State	1912	1913	1914
Alabama	200	100	300
Alaska	539,700	366,700	865,900
Arizona	3,445,500	3,912,000	4,439,500
California	1,384,800	1,421,500	2,020,800
Colorado	7,933,100	8,989,700	8,884,400
Georgia	200	100	100
Idaho	7,862,900	9,477,100	12,573,800
Illinois	1,800	2,300	1,900
Maryland	700	....	100
Michigan	543,500	333,700	415,500
Missouri	30,000	38,900	60,000
Montana	12,524,000	12,540,300	2,536,700
Nevada	13,851,400	15,657,400	15,877,200
New Mexico	1,460,800	1,666,900	1,771,300
North Carolina	2,300	1,700	1,500
Oklahoma	....	800	6,200
Oregon	54,000	172,200	147,400
South Carolina	....	....	....
South Dakota	205,800	172,600	179,800
Tennessee	112,000	109,000	102,800
Texas	379,800	429,800	574,700
Utah	13,076,700	11,282,300	11,722,000
Virginia	700	200	1,500
Washington	350,800	218,700	341,300
Wyoming	300	1,200	100
Continental U. S.	63,761,000	66,796,200	72,444,800
Philippines	5,800	5,300	10,300
Porto Rico	....	....	....
Total	63,766,800	66,801,500	72,455,100

As reported by the Director of the Mint and the U. S. Geological Survey.

Gold Production of the World for 20 Years[1]

1895	$198,995,741	1905	$378,411,054
1896	211,242,081	1906	405,551,022
1897	237,833,984	1907	411,294,458
1898	287,327,833	1908	443,434,527
1899	311,505,947	1909	459,927,482
1900	258,829,703	1910	454,213,649
1901	260,877,429	1911	459,377,300
1902	298,812,493	1912	474,333,268
1903	329,475,401	1913	462,669,658
1904	349,088,293	1914	451,582,129

[1] As tabulated in the *Engineering and Mining Journal*, Jan. 10, 1914.

Gold Production of the World

	1912	1913	1914
Transvaal	$188,599,260	$181,889,012	$173,176,133
Rhodesia	13,166,230	13,935,681	17,745,980
West Africa	7,386,028	7,846,560	8,671,371
Madagascar, etc.	2,925,000	2,044,600	1,980,000
Total Africa	$212,076,518	$205,715,653	$201,573,484
United States	$93,451,500	$88,884,400	94,531,800
Mexico	22,500,000	20,500,000	18,185,000
Canada	12,559,288	16,216,131	15,925,044
Central America, etc.	3,632,500	3,030,400	3,500,000
Total North America	$132,143,288	$128,630,931	$132,141,844
Russia, inc. Siberia	$27,635,500	$29,500,000	26,763,000
France	1,847,000	1,812,100	1,450,000
Other Europe	3,615,000	2,950,000	2,350,000
Total Europe	$33,097,500	$34,262,100	$30,563,000
British India	$12,115,162	$12,176,783	$12,327,980
British and Dutch E. Indies	4,925,000	4,739,100	4,690,000
Japan and Chosen	7,165,000	7,394,300	7,476,500
China and others	3,750,000	3,658,900	3,625,000
Total Asia, not inc. Siberia	$27,955,162	$27,969,083	$28,119,480
South America	$12,425,000	$13,058,400	$13,525,000
Australasia	56,635,800	53,033,391	45,695,271
Total for the world	$474,333,268	$462,669,558	$451,582,129

Official returns of the various countries and reports of the Director of the U.S. Mint.

Gold Production in the United States
(Values)

State	1912	1913	1914
Alabama	$16,400	$9,200	$12,300
Alaska	17,198,600	15,201,300	16,547,200
Arizona	3,785,400	4,101,400	4,568,900
California	20,008,000	20,241,300	21,251,900
Colorado	18,741,200	18,109,700	19,902,400
Georgia	10,900	13,300	16,800
Idaho	1,401,700	1,244,300	1,187,200
Maryland and Virginia	1,200	700	500
Montana	3,707,900	3,320,900	4,143,600
Nevada	13,575,700	11,977,400	11,536,200
New Mexico	754,600	892,000	1,219,100
North Carolina	156,000	115,200	130,300
Oregon	759,700	1,477,900	1,589,400
South Carolina	15,400	4,100	6,400
South Dakota	7,823,700	7,214,200	7,334,000
Tennessee	11,500	7,700	6,400
Texas	2,200	200	18,800
Utah	4,312,600	3,570,300	3,377,000
Washington	682,600	657,500	587,800
Wyoming	24,300	17,500	6,700
Continental U. S.	$92,989,900	$88,176,100	$93,429,700
Philippines	461,600	707,200	1,099,300
Porto Rico	....	1,100	2,800
Total	$93,451,500	$88,884,400	$94,531,800

As reported by the Director of the Mint and the U. S. Geological Survey.

U. S. Pig Iron Production for 12 Years[1]
(In Long Tons)

1903....	18,009,252	1907....	25,781,381	1911....	23,649,547
1904....	16,497,003	1908....	15,936,918	1912....	29,726,937
1905....	22,992,380	1909....	25,795,471	1913....	30,966,152
1906....	25,307,391	1910....	27,303,567	1914....	23,332,244

U. S. Iron Ore Production and Consumption[1]
(In Long Tons)

	1912	1913	1914
Lake Superior shipments....	48,211,778	49,947,116	33,721,897
Southern ore mined........	7,500,000	7,950,000	6,175,000
Eastern and other local ores.	3,485,000	3,950,000	3,015,000
Total production.........	59,196,778	61,847,116	42,911,897
Imports..................	2,104,576	2,594,876	1,455,000
Total supplies...........	61,301,354	64,441,992	44,366,897
Exports..................	1,195,742	1,042,151	660,000
Approximate consumption.	60,105,612	63,399,841	43,706,897

Production of Crude Petroleum in the United States[1]
(In Barrels of 42 Gal.)

Field	1912	1913	1914
California..........	84,823,992	96,881,967	100,093,568
Colorado............	200,000	220,000	(*f*)200,000
Texas (*a*)..........	11,778,324	15,544,046	20,586,377
Louisiana..........	9,791,896	12,901,703	16,860,235
Illinois.............	28,400,000	(*e*)23,893,899	21,500,000
Lima { Indiana.....	1,200,000	4,750,000	2,900,000
Lima { Ohio........	3,000,000		
Mid-continental (*b*).	52,771,603	64,556,000	(*d*)97,400,000
Kentucky-Tennessee	500,000	500,000	580,000
Appalachian (*c*).....	26,000,000	25,673,000	23,800,000
Wyoming..........	500,000	2,354,000	4,100,000
Others.............	5,000	50,000	(*f*)50,000
Total............	218,970,815	247,321,615	288,070,180

(*a*) Includes Panhandle field of Texas. (*b*) Kansas and Oklahoma, only. (*c*) Pennsylvania, New York, West Virginia and eastern Ohio. (*d*) Estimate of Dr. David T. Day, in "Oil, Paint and Drug Reporter," Jan. 2, 1915. (*e*) U. S. Geol. Survey. (*f*) Estimated.

[1] As reported by the *Engineering and Mining Journal.*

Tin Production and Consumption
(In Long Tons)

	1913	1914	1915
Exports, Straits and Malay Peninsula	62,242	61,986	66,760
Exports, Australian	3,253	1,771	2,275
Banka and Billiton sales	17,142	10,975	15,093
Chinese exports and production[1]	8,200	8,255	7,097
Bolivian exports[1]	22,719	24,844	18,800
South African production[1]	1,900	2,276	2,158
Nigerian production[1]	....	1,962	1,899
Cornwall production[1]	4,900	4,500	4,000
Total	120,356	116,569	118,082
U. S. imports and consumption	45,900	42,995	49,480
Great Britain, imports and consumption	28,736	30,531	39,937
Holland, imports	16,573	15,810	7,625
Other Europe, imports	21,250	18,633	11,550
Australian consumption	1,000	1,050	1,100
China and India consumption	6,500	6,400	6,650
Totals	119,959	115,419	116,342
Visible stocks, Dec. 1	16,045	13,432	14,535

[1] Not in "Statistics."

World's Production of Tin
(In Metric Tons)
(From statistical report of the Metallgesellschaft, Frankfurt am Main)

	1911	1912	1913
Straits Settlements	57,944	61,528	65,640
Great Britain:			
From home ores	4,950	5,338	(*c*)5,300
From other ores (*a*)	13,850	13,600	16,700
Germany (*a*)	11,378	11,000	(*c*)11,500
France	500	500	1,200
Banca (sold in Holland)	15,147	16,111	15,173
Billiton (sold in Holland and Java)	2,240	2,243	2,243
Australia	5,150	5,130	4,870
China (exports)	6,050	8,782	(*c*)6,000
Bolivia (*b*)	400	500	300
	117,600	124,700	128,900

(*a*) Mainly from Bolivian ores. (*b*) Importation of Bolivian crude tin into Great Britain. (*c*) Estimated.

World's Consumption of Tin
(In Metric Tons)
(From statistical report of the Metallgesellschaft, Frankfurt am Main)

	1911	1912	1913
Great Britain	21,900	21,800	24,400
Germany	18,300	20,200	19,300
France	7,400	7,500	8,300
Austria-Hungary	4,000	3,800	3,200
Belgium	1,700	1,500	2,300
Russia	1,900	2,600	2,700
Italy	2,400	2,500	2,900
Switzerland	1,200	1,400	1,400
Spain	1,200	1,300	1,300
Scandinavia	1,400	1,500	1,600
Holland	(*a*)250	(*a*)250	(*a*)250
Other European countries	1,200	1,100	1,200
Total Europe	62,800	65,500	68,900
United States	48,000	51,700	45,000
Other America	2,300	3,300	3,400
Australia	(*a*)900	(*a*)1,200	(*a*)1,400
Africa	(*a*)500	(*a*)600	(*a*)500
China (imports)	1,993	2,427	(*a*)2,400
Other Asia	3,000	3,000	3,300
World's consumption	119,500	127,700	124,900
World's production	117,600	124,700	128,900

(*a*) Estimated.

Copper Smelting Works of North America[1]

Company	Situation of works	No. of blast furnaces	Annual capacity tons of charge	No. of reverberatory furnaces	Annual capacity tons of charge	No. of converters	Annual capacity in ore tons (a)
American Smelting & Refining Co	Aguascalientes, Mex.	8	730,000	......	....	4	(b)
American Smelting & Refining Co	Perth Amboy, N. J.	3	111,000	......	....	2	(b)
American Smelting & Refining Co	Omaha, Neb.	....	....	......	....	3	....
American Smelting & Refining Co	El Paso, Texas	3	250,000	3	420,000	3	(b)
American Smelting & Refining Co	Matehuala, S.L.P., Mex.	3	325,000	......	....	...	....
American Smelting & Refining Co	Hayden, Ariz.	....	....	2	290,000	3	(b)
American Smelters Securities Co	Garfield, Utah	4	800,000	6	875,000	6	(b)
American Smelters Securities Co	Tacoma, Wash.	2	420,000	......	....	6	(b)
American Smelters Securities Co	Velardeña, Dgo., Mex.	3	227,500	......	....	...	....
Anaconda Copper Mining Co	Anaconda, Mont.	3	1,800,000	8	800,000	12	85,000
Anaconda Copper Mining Co	Great Falls, Mont.	5	800,000	3	250,000	3	34,500
Arizona Copper Co	Clifton, Ariz.	....	....	3	360,000	3	....
Balakala Consolidated Copper Co (h)	Coram, Calif.	3	630,000	1	52,500	2	....
Compagnie du Boleo	Santa Rosalia, Mex.	8	650,000	......	....	...	....
British Columbia Copper Co	Greenwood, B. C.	3	700,000	......	....	2	....
Calumet & Arizona Mining Co	Douglas, Ariz.	2	634,900	4	471,700	6	40,500
Canadian Copper Co	Copper Cliff, Ont.	6	940,000	2	300,000	5	(g)
Cananea Consolidated Copper Co	Cananea, Son.	8	868,000	2	153,000	6	35,000
Consolidated Arizona Smelting Co	Humboldt, Ariz.	....	....	1	500,000	1	3,000
Consolidated Mining & Smelting Co	Trail, B. C.	5	450,000	......	....	...	....
Copper Queen Consolidated Copper Co	Douglas, Ariz.	10	1,225,000	3	275,000	7	34,160
Detroit Copper Mining Co	Morenci, Ariz.	1	132,657	......	....	3	7,578
Ducktown Sulphur, Copper & Iron Co	Isabella, Tenn.	2	171,500	......	....	...	....
East Butte Copper Mining Co	Butte, Mont.	2	310,250	......	....	3	7,300
Granby Consolidated Mining, Smelting & Power Co.	Grand Forks, B. C.	8	1,440,000	......	....	6	7,000
Granby Consolidated Mining, Smelting & Power Co.	Anyox, B. C.	3	700,000	......	....	3	....
International Smelting Co	Tooele, Utah	....	....	5	456,250	5	25,450
International Smelting Co	Miami, Ariz. (d)	....	....	3	262,500	5	....
Mammoth Copper Mining Co	Kennett, Calif.	5	730,000	......	....	2	18,250

COPPER SMELTING WORKS OF NORTH AMERICA.[1]—*Concluded*

Company	Situation of works	No. of blast furnaces	Annual capacity tons of charge	No. of reverberatory furnaces	Annual capacity tons of charge	No. of converters	Annual capacity in ore tons (*a*)
Mason Valley Mines Co.	Thompson, Nev.	2	800,000	....	....	2	22,000
Mazapil Copper Co. (*h*)	Saltillo, Coah., Mex.	4	350,000	1	52,500	4	....
Mond Nickel Co.	Coniston, Ont.	3	630,000	....	....	3	70,000
Mountain Copper Co.	Martinez, Calif.	.....	....	3	125,000	2	(*g*)
Nevada Consolidated Copper Co.	McGill, Nev.	1	175,000	5	900,000	4	40,000
Nichols Copper Co.	Laurel Hill, N. Y.	2	94,500	....	....	2	....
Old Dominion Copper Mining & Smelting Co.	Globe, Ariz.	5	562,500	....	....	3	8,400
Orford Works, International Nickel Co.	Constable Hook, N. J.	2	94,500	....	....	3	....
Wanakah Mining Co.	Ouray, Colo.	2	105,000	....	....	....	....
Penn Mining Co.	Campo Seco, Calif.	1	50,000	2(*e*)	48,000	....	....
Pioneer Smelting Co.	Corwin, Ariz.	1	60,000	....	....	....	....
Santa Fe Gold & Copper Co.	San Pedro, N. M.	1	52,500	....	....	....	....
Shannon Copper Co.	Clifton, Ariz.	3	500,000	....	....	2	8,000
Swansea Consolidated Gold & Copper Mining Co.	Bouse, Ariz.	1	190,000	....	....	2	....
Tennessee Copper Co.	Copperhill, Tenn.	7	1,000,000	....	....	4	15,700
Teziutlan Copper Mining & Smelting Co. (*h*)	Teziutlan, Puebla, Mex.	2	350,000	....	....	3	....
Cia. Metalurgica de Torreon	Torreon, Coah., Mex.	2	175,000	....	....	2	....
Tyee Copper Co. (*h*)	Ladysmith, B. C.	2	175,000	....	....	....	....
U. S. Metals Ref. Co.	Chrome, N. J.	2	200,000	....	....	2	....
U. S. Smelting Co. (*h*)	Midvale, Utah	6	670,000	1	40,000	4	36,000
Virginia Smelting Co.	West Norfolk, Va. (*f*)	1	200,000	....	....	....	....
United Verde Copper Co. (*c*)	Jerome, Ariz.	4	427,300	....	....	4	37,600
United Verde Copper Co.	Clarkdale, Ariz. (*d*)	4	720,000	3	285,000	5	75,000

(*a*) Raw ore smelted as flux. (*b*) Included in furnace tonnages. (*c*) To be abandoned by Jan. 1, 1915. (*d*) Plants building. (*e*) Penn Min. Co. has 2 reverberatories, each with capacity of 48,000 tons per annum, but only one is run at a time. (*f*) Operated by Norfolk Smelting Co., Inc. (*g*) No raw ore charged. (*h*) Not in operation.

[1] *Engineering and Mining Journal*, Jan. 10, 1914.

Electrolytic Copper Refineries of the United States

Works	Situation	1911 capacity, pounds	1912 capacity, pounds	1913 capacity, pounds (c)	1914 capacity, pounds (c)
Nichols Copper Co.	Laurel Hill, N. Y.	(b) 333,000,000	(a) 400,000,000	400,000,000	400,000,000
Raritan Copper Works	Perth Amboy, N. J.	(a) 320,000,000	(b) 360,000,000	400,000,000	400,000,000
Baltimore Copper Smelting & Rolling Co.	Canton, Md.	(b) 288,000,000	(a) 312,000,000	348,000,000	336,000,000
American Smelting & Refining Co.	Perth Amboy, N. J.	(b) 180,000,000	(a) 192,000,000	216,000,000	216,000,000
U. S. Metals Refining Co.	Chrome, N. J.	(a) 180,000,000	(a) 180,000,000	200,000,000	200,000,000
Balbach Smelting & Refining Co.	Newark, N. J.	(a) 48,000,000	(a) 48,000,000	48,000,000	48,000,000
Anaconda Copper Mining Co.	Great Falls, Mont.	(b) 65,000,000	(a) 65,000,000	65,000,000	65,000,000
Tacoma Smelting Co.	Tacoma, Wash.	(b) 28,000,000	(a) 36,000,000	36,000,000	48,000,000
Calumet & Hecla Mining Co.	Buffalo, N. Y.	(a) 55,000,000	(a) 55,000,000	55,000,000	(d)
Calumet & Hecla Mining Co.	Calumet, Mich.	....	....	....	(e) 65,000,000
Total	....	1,494,000,000	1,648,000,000	1,768,000,000	1,778,000,000

(a) Official figures furnished by the respective companies. (b) Estimated. (c) All of the figures for 1913 and 1914 were officially furnished. (d) Buffalo works at Calumet & Hecla dismantled in fall of 1914. (e) New works put into operation in 1914.

SECTION III
PHYSICAL CONSTANTS

The Fundamental Laws of Physics

Force = mass × acceleration; $f = ma$
Momentum = mass × velocity; $M = mv$
Energy = ½ mass × velocity²; $E = \frac{1}{2}mv^2$
Work = force × distance = $fs = mas$

Harmonic motion, period $= 2\pi\sqrt{\dfrac{\text{length}}{\text{acceleration}}}$, or in a pendulum

$$T = 2\pi\sqrt{\frac{l}{g}}$$

Laws of a falling body: v = velocity at end of t seconds, S = space traversed in t seconds, S_t = space traversed from t to $(t + 1)$ seconds

$$v = gt$$
$$S = \tfrac{1}{2}gt^2$$
$$S_t = \tfrac{1}{2}g(2t + 1)$$

"Centrifugal force" = $mr\omega^2$, where ω = angular velocity.

Torsional pendulum: $T = 2\pi\sqrt{\dfrac{2lI}{\pi n r^4}}$

where T = period, l = length, I = moment of inertia of mass on end, n = coefficient of rigidity, r = radius of wire.

Young's modulus, coefficient of elasticity:

$$F_1 = \frac{p}{\frac{\Delta l}{l}} = \frac{fl}{\pi r^2 \Delta l};$$

l = length, Δl = change in length.

Pressure in liquids = ρgh, where ρ = density and h = height of column.

Speed of escape of a liquid from an orifice, if there were no viscosity,

$$S = \sqrt{\frac{2p}{\rho}}$$

Boyle's law, behavior of perfect gases under varying volumes, pressures and temperatures:

$pv = RmT$, where R is the so-called gas constant and T is absolute temperature.

Under changes so sudden that the heat generated by compression (or absorbed by expansion) cannot radiate or be absorbed from external objects:

$$pv^\gamma = Rmt$$

Electricity: Ampere, the unit of current strength, I; volt, the unit of electromotive force, E; ohm, the unit of resistance, R; coulomb, the unit of quantity, Q; watt, the unit of power, P; joule, the unit of work, J; farad, the unit of capacity, C; henry, the unit of inductance, l. t = seconds. $I = \frac{E}{R}$ (Ohm's law); $Q = It$, $C = \frac{Q}{E}$, $W = QE$, $P = IE$, $P = \frac{E^2}{R} = I^2R = \frac{W}{t} = \frac{QE}{t}$.

Heating effect of a current $= i^2Rt = \frac{E^2t}{R}$.

COMPOSITION OF THE AIR[1]

	By weight	By volume	Expired air by volume
Oxygen	23.024	20.941	15.4
Nitrogen	75.539	78.122	79.2
Argon[2]	1.337	0.937	
CO_2	0.040	....	4.33

PYSCHROMETRIC TABLES[3]

Measurement of Atmospheric Moisture.—The quantity of moisture mixed with the air under different conditions of temperature and degree of saturation may be measured in several distinctly different ways. Many of these, however, are not practicable methods for daily observations, or are not sufficiently accurate. Probably the most convenient of all methods and the one most generally employed is to observe the temperature of evaporation—that is, the difference between the temperatures indicated by wet- and dry-bulb thermometers. The most reliable instrument for this purpose is the sling, or whirled psychrometer. In special cases, rotary fans or other means may be employed to move the air rapidly over the thermometer bulbs. In any case satisfactory results cannot be obtained from observations in relatively stagnant air. A strong ventilation is absolutely necessary to accuracy.

Sling Psychrometer.—This instrument consists of a pair of thermometers, provided with a handle, which permits the thermometers to be whirled rapidly, the bulbs being thereby strongly affected by the temperature of and moisture in the air. The bulb of the lower of the two thermometers is covered with thin muslin, which is wet at the time an observation is made.

The Wet Bulb.—It is important that the muslin covering for

[1] According to RAMSAY (cf. BENSON'S "Industrial Chemistry," p. 38. The Macmillan Co.)

[2] Including the other inert gases. The rare gases are present in air in the following proportions by weight: krypton, 0.028 per cent.; xenon, 0.005; neon, 0.00038; helium, 0.000056 per cent.

[3] C. F. MARVIN'S Tables, Weather Bureau Bulletin No. 235.

Continued on page 78.

Temperature of Dew-point in Degrees Fahrenheit

Pressure = 30.0 inches of mercury

Air temp., t	Vapor press., in., Hg.	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0
		Depression of wet-bulb thermometer $(t-t')$														
—40	0.0039	—52														
—39	41	—50														
—38	44	—49														
—37	46	—48														
—36	48	—46														
—35	0.0051	—45														
—34	54	—43	—59													
—33	57	—42	—56													
—32	61	—40	—53													
—31	65	—38	—50													
—30	0.0069	—36	—47													
—29	74	—35	—45													
—28	78	—33	—42	—58												
—27	83	—32	—40	—54												
—26	89	—30	—38	—50												
—25	0.0094	—29	—36	—46												
—24	0.0100	—28	—34	—43	—60											
—23	106	—27	—32	—40	—54											
—22	112	—26	—31	—38	—49											
—21	119	—25	—29	—35	—45											
—20	0.0126	—23	—28	—33	—42	—57										
—19	133	—22	—26	—31	—39	—51										
—18	141	—21	—25	—29	—36	—46										
—17	150	—20	—23	—28	—33	—42	—59									
—16	159	—19	—22	—26	—31	—38	—51									
—15	0.0168	—18	—21	—24	—29	—35	—45									
—14	178	—16	—19	—23	—27	—32	—40	—56								
—13	188	—15	—18	—21	—25	—30	—36	—48								
—12	199	—14	—17	—20	—23	—27	—33	—43	—59							
—11	210	—13	—16	—18	—22	—25	—30	—38	—50							
—10	0.0222	—12	—14	—17	—20	—24	—28	—33	—44							
— 9	234	—11	—13	—16	—18	—22	—26	—30	—38	—51						
— 8	247	—10	—12	—14	—17	—20	—24	—28	—34	—44						
— 7	260	— 9	—11	—13	—16	—18	—22	—26	—31	—38	—51					
— 6	275	— 8	—10	—12	—14	—17	—20	—23	—28	—33	—44					
— 5	0.0291	— 7	— 8	—10	—13	—15	—18	—21	—25	—30	—37	—50				
— 4	307	— 6	— 7	— 9	—11	—14	—16	—19	—22	—27	—32	—42	—59			
— 3	325	— 4	— 6	— 8	—10	—12	—14	—17	—20	—24	—29	—35	—47			
— 2	344	— 3	— 5	— 7	— 8	—10	—13	—15	—18	—21	—25	—30	—38	—53		
— 1	363	— 2	— 4	— 5	— 7	— 9	—11	—13	—16	—19	—22	—27	—32	—42	—60	
0	0.0383	— 1	— 3	— 4	— 6	— 7	— 9	—12	—14	—17	—20	—23	—28	—35	—46	
+ 1	403	± 0	— 2	— 3	— 4	— 6	— 8	—10	—12	—15	—17	—20	—25	—30	—37	—50
2	423	+ 1	— 1	— 2	— 3	— 5	— 6	— 8	—10	—13	—15	—18	—21	—26	—31	—40
3	444	2	+ 1	— 1	— 2	— 4	— 5	— 7	— 9	—11	—13	—16	—19	—22	—27	—32
4	467	3	2	± 0	— 1	— 2	— 4	— 5	— 7	— 9	—11	—14	—16	—19	—23	—28
5	0.0491	4	3	+ 1	± 0	— 1	— 3	— 4	— 6	— 7	— 9	—12	—14	—17	—20	—24
6	515	5	4	3	+ 1	± 0	— 1	— 3	— 4	— 6	— 8	—10	—12	—15	—17	—21
7	542	6	5	4	2	+ 1	± 0	— 1	— 3	— 4	— 6	— 8	—10	—12	—15	—18
8	570	7	6	5	4	3	+ 1	± 0	— 2	— 3	— 5	— 6	— 8	—10	—13	—15
9	600	8	7	6	5	4	3	+ 1	± 0	— 2	— 3	— 5	— 6	— 8	—10	—13
10	0.0631	9	8	7	6	5	4	3	+ 1	± 0	— 2	— 3	— 5	— 6	— 8	—10
11	665	10	9	8	7	6	5	4	3	+ 1	± 0	— 1	— 3	— 4	— 6	— 8
12	699	11	10	9	8	7	6	5	4	3	+ 2	± 0	— 1	— 3	— 4	— 6
13	735	12	11	11	10	9	8	7	6	4	3	+ 2	± 0	— 1	— 2	— 4
14	772	13	12	12	11	10	9	8	7	6	5	3	+ 2	+ 1	— 1	— 2
15	0.0810	14	13	13	12	11	10	9	8	7	6	5	4	2	— 1	— 0
16	850	15	14	14	13	12	11	10	9	8	7	6	5	4	+ 3	± 1
17	891	16	15	15	14	13	12	12	11	10	9	8	7	6	4	3
18	933	17	17	16	15	14	13	13	12	11	10	9	8	7	6	5
19	0.0979	18	18	17	16	15	15	14	13	12	11	10	9	8	7	6
20	0.1026	19	19	18	17	16	16	15	14	13	12	12	11	10	9	8

t	e	t	e	$(t-t')$ 0.1	0.2	0.3	0.4	0.5
—60	0.0010	—50	0.0021	—60				
—59	11	—49	22	—58				
—58	12	—48	24	—56				
—57	13	—47	26	—55				
—56	13	—46	27	—53				
—55	0.0015	—45	0.0029	—51				
—54	16	—44	31	—50	—60			
—53	17	—43	33	—49	—58			
—52	18	—42	35	—48	—56			
—51	0.0019	—41	37	—46	—54			
		—40	0.0039	—45	—52			
		—39	41	—44	—50			
		—38	44	—43	—49	—59		
		—37	46	—42	—48	—56		
		—36	48	—41	—46	—54		
		—35	0.0051	—40	—45	—51		
		—34	54	—38	—43	—49	—59	
		—33	57	—37	—42	—47	—56	
		—32	61	—35	—40	—46	—53	
		—31	65	—34	—38	—44	—50	—60
		—30	0.0069	—33	—36	—42	—47	—55

Temperature of Dew-point in Degrees Fahrenheit. *Continued*

Pressure = 30.0 inches of mercury

Air temp., t	Depression of wet-bulb thermometer $(t - t')$														
	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0	5.2	5.4	5.6	5.8	6.0
2	—56														
3	—43														
4	—34	—46													
5	—29	—36	—49												
6	—25	—30	—39	—53											
7	—21	—26	—31	—41	—58										
8	—18	—22	—26	—32	—42										
9	—15	—19	—22	—27	—33	—44									
10	—13	—16	—19	—23	—27	—34	—45								
11	—10	—13	—16	—19	—22	—27	—34	—46							
12	— 8	—10	—13	—15	—19	—22	—27	—34	—47						
13	— 6	— 8	—10	—12	—15	—18	—22	—27	—34	—46					
14	— 4	— 6	— 8	—10	—12	—15	—18	—22	—27	—33	—45				
15	— 2	— 4	— 5	— 7	— 9	—12	—15	—18	—21	—26	—32	—44			
16	± 0	— 2	— 3	— 5	— 7	— 9	—11	—14	—17	—20	—25	—31	—42		
17	+ 2	± 0	— 1	— 3	— 4	— 6	— 8	—11	—13	—16	—20	—24	—30	—39	—5
18	+ 3	+ 2	+ 1	— 1	— 2	— 4	— 6	— 8	—10	—13	—16	—19	—23	—29	—3
19	+ 5	+ 4	+ 3	+ 1	± 0	— 2	— 4	— 5	— 7	—10	—12	—15	—18	—22	—2
20	+ 7	+ 6	+ 4	+ 3	+ 2	± 0	— 1	— 3	— 5	— 7	— 9	—11	—14	—17	—2

the wet bulb be kept in good condition. The evaporation o the water from the muslin always leaves in its meshes a smal quantity of solid material, which sooner or later somewhat stif fens the muslin so that it does not readily take up water. Thi will be the case if the muslin does not readily become wet afte being dipped in water. On this account it is desirable to use a pure water as possible, and also to renew the muslin from tim to time. New muslin should always be washed to remov sizing, etc., before being used. A small rectangular piece wid enough to go about one and one-third times around the bulb and long enough to cover the bulb and that part of the sten below the metal back, is cut out, *thoroughly wetted* in clea water, and neatly fitted around the thermometer. It is tied firs around the bulb at the top, using a moderately strong thread A loop of thread to form a knot is next placed around the bot tom of the bulb, just where it begins to round off. As thi knot is drawn tighter and tighter the thread slips off the rounde end of the bulb and neatly stretches the muslin covering with it at the same time securing the latter at the bottom.

To Make an Observation.—The so-called wet bulb is thor oughly saturated with water by dipping it into a small cup The thermometers are then whirled rapidly for 15 or 20 seconds stopped and quickly read, the *wet bulb* first. This reading i kept in mind, the psychrometer immediately whirled again an a second reading taken. This is repeated three or four times, o more, if necessary, until at least two succeeding readings of th

Continued on page 98.

Temperature of Dew-point in Degrees Fahrenheit.
Continued
Pressure = 30.0 inches of mercury

Air temp., t	Vapor press. in., Hg.	Depression of wet-bulb thermometer $(t - t')$														
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5
20	0.103	18	16	14	12	10	8	5	2	−2	−7	−13	−21	−37		
21	0.108	19	18	16	14	12	9	7	3	±0	−4	−9	−16	−27	−60	
22	0.113	20	19	17	15	13	11	8	5	+2	−2	−6	−12	−20	−36	
23	0.118	21	20	18	16	14	12	10	7	4	±0	−4	−9	−16	−26	−57
24	0.124	23	21	19	17	15	13	11	9	6	+2	−1	−6	−12	−20	−35
25	0.130	24	22	20	19	17	15	13	10	8	5	+1	−3	−8	−15	−25
26	0.136	25	23	22	20	18	16	14	12	9	7	3	−1	−5	−11	−18
27	0.143	26	24	23	21	19	18	16	13	11	8	5	+2	−2	−7	−14
28	0.150	27	25	24	22	21	19	17	15	13	10	7	4	±0	−4	−9
29	0.157	28	26	25	23	22	20	18	16	14	12	9	6	+3	−1	−5
30	0.164	29	27	26	25	23	21	20	18	16	14	11	8	5	+2	−2
31	0.172	30	28	27	26	24	23	21	19	17	15	13	10	8	4	±0
32	0.180	31	30	28	27	25	24	22	21	19	17	15	12	10	7	+3
33	0.187	32	31	29	28	27	25	24	22	20	18	16	14	12	9	6
34	0.195	33	32	30	29	28	26	25	23	22	20	18	16	13	11	8
35	0.203	34	33	31	30	29	28	26	25	23	21	19	17	15	13	10
36	0.211	35	34	32	31	30	29	27	26	24	23	21	19	17	15	12
37	0.219	36	35	33	32	31	30	28	27	26	24	22	21	19	17	14
38	0.228	37	36	34	33	32	31	29	28	27	25	24	22	20	18	16
39	0.237	38	37	35	34	33	32	31	29	28	27	25	23	22	20	18
40	0.247	39	38	37	35	34	33	32	30	29	28	26	25	23	21	20
41	0.256	40	39	38	36	35	34	33	31	30	29	27	26	24	23	21
42	0.266	41	40	39	38	36	35	34	33	31	30	29	27	26	24	23
43	0.277	42	41	40	39	37	36	35	34	32	31	30	28	27	25	24
44	0.287	43	42	41	40	38	37	36	35	34	32	31	30	28	27	25
45	0.298	44	43	42	41	40	38	37	36	35	34	32	31	30	28	27
46	0.310	45	44	43	42	41	40	38	37	36	35	33	32	31	29	28
47	0.322	46	45	44	43	42	41	40	38	37	36	35	33	32	31	29
48	0.334	47	46	45	44	43	42	41	40	38	37	36	35	33	32	31
49	0.347	48	47	46	45	44	43	42	41	40	38	37	36	34	33	32
50	0.360	49	48	47	46	45	44	43	42	41	40	38	37	36	34	33
51	0.373	50	49	48	47	46	45	44	43	42	41	40	38	37	36	34
52	0.387	51	50	49	48	47	46	45	44	43	42	41	40	38	37	36
53	0.402	52	51	50	49	48	47	46	45	44	43	42	41	40	38	37
54	0.417	53	52	51	50	49	48	47	46	45	44	43	42	41	40	38
55	0.432	54	53	52	51	50	50	49	48	47	45	44	43	42	41	40
56	0.448	55	54	53	53	52	51	50	49	48	47	46	44	43	42	41
57	0.465	56	55	54	54	53	52	51	50	49	48	47	46	45	43	42
58	0.482	57	56	55	55	54	53	52	51	50	49	48	47	46	45	44
59	0.499	58	57	56	56	55	54	53	52	51	50	49	48	47	46	45
60	0.517	59	58	57	57	56	55	54	53	52	51	50	49	48	47	46
61	0.536	60	59	59	58	57	56	55	54	53	52	51	50	49	48	47
62	0.555	61	60	60	59	58	57	56	55	54	53	53	52	51	50	48
63	0.575	62	61	61	60	59	58	57	56	55	55	54	53	52	51	50
64	0.595	63	62	62	61	60	59	58	57	57	56	55	54	53	52	51
65	0.616	64	63	63	62	61	60	59	59	58	57	56	55	54	53	52
66	0.638	65	64	64	63	62	61	60	60	59	58	57	56	55	54	53
67	0.661	66	65	65	64	63	62	62	61	60	59	58	57	56	55	54
68	0.684	67	67	66	65	64	63	63	62	61	60	59	58	57	57	56
69	0.707	68	68	67	66	65	64	64	63	62	61	60	59	59	58	57
70	0.732	69	69	68	67	66	65	65	64	63	62	61	61	60	59	58
71	0.757	70	70	69	68	67	67	66	65	64	63	62	62	61	60	59
72	0.783	71	71	70	69	68	68	67	66	65	64	64	63	62	61	60
73	0.810	72	72	71	70	69	69	68	67	66	66	65	64	63	62	61
74	0.838	73	73	72	71	70	70	69	68	67	67	66	65	64	63	62
75	0.866	74	74	73	72	71	71	70	69	68	68	67	66	65	64	64
76	0.896	75	75	74	73	72	72	71	70	69	69	68	67	66	66	65
77	0.926	76	76	75	74	73	73	72	71	71	70	69	68	67	67	66
78	0.957	77	77	76	75	75	74	73	72	72	71	70	69	69	68	67
79	0.989	78	78	77	76	76	75	74	73	73	72	71	70	70	69	68
80	1.022	79	79	78	77	77	76	75	74	74	73	72	72	71	70	69

Temperature of Dew-point in Degrees Fahrenheit. *Continued*

Pressure = 30.0 inches of mercury

Air temp., t	Vapor press., in., Hg.	Depression of wet-bulb thermometer (t − t′) 8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
25	0.130	−51														
26	0.136	−32														
27	0.143	−23	−45													
28	0.150	−17	−29													
29	0.157	−12	−20	−39												
30	0.164	− 7	−14	−25	−57											
31	0.172	− 4	−10	−18	−31											
32	0.180	− 1	− 6	−12	−21	−42										
33	0.187	+ 2	− 2	− 7	−14	−26										
34	0.195	5	+ 1	− 3	− 9	−17	−32									
35	0.203	7	4	± 0	− 5	−11	−20	−41								
36	0.211	10	7	+ 3	− 1	− 6	−14	−25	−58							
37	0.219	12	9	6	+2	− 3	− 8	−16	−29							
38	0.228	14	11	8	5	+ 1	− 4	−10	−19	−36						
39	0.237	16	13	11	8	4	± 0	− 5	−12	−22	−47					
40	0.247	18	15	13	10	7	+ 3	− 1	− 6	−14	−26					
41	0.256	19	17	15	12	10	6	+ 2	− 2	− 8	−16	−30				
42	0.266	21	19	17	14	12	9	6	+ 2	− 3	− 9	−18	−36			
43	0.277	22	20	19	16	14	11	9	5	+ 1	− 4	−11	−21	−45		
44	0.287	24	22	20	18	16	13	11	8	4	± 0	− 5	−12	−24	−60	
45	0.298	25	23	22	20	18	15	13	10	7	+ 4	− 1	− 6	−14	−27	
46	0.310	27	25	23	21	20	17	15	13	10	7	+ 3	− 2	− 7	−16	−30
47	0.322	28	26	25	23	21	19	17	15	12	9	6	+ 2	− 3	− 9	−17
48	0.334	29	28	26	25	23	21	19	17	14	12	9	5	+ 1	− 4	−10
49	0.347	30	29	28	26	24	23	21	19	16	14	11	8	5	± 0	− 5
50	0.360	32	30	29	27	26	24	22	21	18	16	13	11	8	+ 4	± 0
51	0.373	33	32	30	29	27	26	24	22	20	18	16	13	10	7	+3
52	0.387	34	33	32	30	29	27	26	24	22	20	18	16	13	10	7
53	0.402	36	34	33	32	30	29	27	26	24	22	20	18	15	13	10
54	0.417	37	36	34	33	32	30	29	27	25	24	22	20	18	15	12
55	0.432	38	37	36	34	33	32	30	29	27	25	24	22	20	17	15
56	0.448	40	39	37	36	34	33	32	30	29	27	25	24	22	19	17
57	0.465	41	40	39	37	36	34	33	32	30	29	27	25	24	21	19
58	0.482	42	41	40	39	37	36	35	33	32	30	29	27	25	23	21
59	0.499	44	43	41	40	39	37	36	35	33	32	30	29	27	25	23
60	0.517	45	44	43	41	40	39	38	36	35	33	32	30	29	27	25
61	0.536	46	45	44	43	42	40	39	38	36	35	33	32	30	29	27
62	0.555	47	46	45	44	43	42	40	39	38	36	35	33	32	30	29
63	0.575	49	48	47	45	44	43	42	41	39	38	36	35	34	32	30
64	0.595	50	49	48	47	46	44	43	42	41	39	38	37	35	34	32
65	0.616	51	50	49	48	47	46	45	43	42	41	40	38	37	35	34
66	0.638	52	51	50	49	48	47	46	45	44	42	41	40	38	37	35
67	0.661	53	53	52	50	49	48	47	46	45	44	43	41	40	38	37
68	0.684	55	54	53	52	51	50	49	48	46	45	44	43	42	40	39
69	0.707	56	55	54	53	52	51	50	49	48	46	45	44	43	42	40
70	0.732	57	56	55	54	53	52	51	50	49	48	47	46	44	43	42
71	0.757	58	57	56	55	54	53	52	51	50	49	48	47	46	45	43
72	0.783	59	58	58	57	56	55	54	53	52	51	50	48	47	46	45
73	0.810	60	60	59	58	57	56	55	54	53	52	51	50	49	48	46
74	0.838	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48
75	0.866	63	62	61	60	59	58	57	56	55	55	54	52	51	50	49
76	0.896	64	63	62	61	60	60	59	58	57	56	55	54	53	52	51
77	0.926	65	64	63	62	62	61	60	59	58	57	56	55	54	53	52
78	0.957	66	65	64	64	63	62	61	60	59	58	57	56	55	54	53
79	0.989	67	66	66	65	64	63	62	61	60	59	59	58	57	56	55
80	1.022	68	68	67	66	65	64	63	63	62	61	60	59	58	57	56

Temperature of Dew-point in Degrees Fahrenheit. *Continued*

Pressure = 30.0 inches of mercury

Air temp., t	Depression of wet-bulb thermometer (t − t′)														
	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5
47	−35														
48	−20	−41													
49	−12	−22	−53												
50	− 6	−13	−26												
51	− 1	− 7	−15	−29											
52	+ 3	− 2	− 8	−17	−33										
53	7	+ 2	− 3	− 9	−18	−39									
54	10	6	+ 2	− 4	−10	−20	−47								
55	12	9	6	+ 1	− 4	−12	−23	−59							
56	15	12	9	5	+ 1	− 5	−13	−25							
57	17	14	12	9	5	± 0	− 6	−14	−27						
58	19	17	14	11	8	+ 4	− 1	− 6	−15	−30					
59	21	19	17	14	11	8	+ 4	− 1	− 7	−16	−33				
60	23	21	19	17	14	11	8	+ 4	− 2	− 8	−17	−36			
61	25	23	21	19	17	14	11	8	+ 3	− 2	− 8	−18	−40		
62	27	25	23	21	19	16	14	11	7	+ 3	− 2	− 9	−19	−45	
63	29	27	25	23	21	19	17	14	11	7	+ 3	− 2	− 9	−20	−49
64	31	29	27	25	23	21	19	17	14	11	7	+ 3	− 3	−10	−21
65	32	31	29	27	25	24	21	19	17	14	11	7	+ 3	− 3	−10
66	34	32	31	29	27	26	24	22	19	17	14	11	7	+ 2	− 3
67	36	34	32	31	29	28	26	24	22	19	17	14	11	7	+ 2
68	37	36	34	33	31	29	28	26	24	22	19	17	14	11	7
69	39	37	36	34	33	31	30	28	26	24	22	19	17	14	11
70	40	39	38	36	34	33	31	30	28	26	24	22	20	17	14
71	42	41	39	38	36	35	33	31	30	28	26	24	22	20	17
72	44	42	41	40	38	37	35	33	32	30	28	26	24	22	20
73	45	44	43	41	40	38	37	35	34	32	30	28	27	25	22
74	47	45	44	43	41	40	39	37	35	34	32	30	29	27	25
75	48	47	46	44	43	42	40	39	37	36	34	32	31	29	27
76	49	48	47	46	45	43	42	41	39	38	36	34	33	31	29
77	51	50	49	48	46	45	44	42	41	39	38	36	35	33	31
78	52	51	50	49	48	46	45	44	43	41	40	38	37	35	33
79	54	53	52	50	49	48	47	46	44	43	42	40	38	37	35
80	55	54	53	52	51	50	48	47	46	44	43	42	40	39	37

t	Depression of wet-bulb thermometer (t − t′)														
	23.0	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0
64	−54														
65	−22														
66	−11	−22													
67	− 3	−11	−23												
68	+ 2	− 3	−11	−24											
69	7	+ 2	− 3	−11	−24										
70	11	7	+ 2	− 3	−11	−24									
71	14	11	7	+ 3	− 3	−11	−24								
72	17	14	11	7	+ 3	− 3	−11	−24							
73	20	17	15	11	8	+ 3	− 3	−11	−24						
74	23	20	18	15	12	8	+ 3	− 3	−10	−24					
75	25	23	21	18	15	12	8	+ 4	− 2	−10	−23				
76	27	25	23	21	18	15	12	8	+ 4	− 2	−10	−22			
77	29	28	26	23	21	18	16	13	9	+ 4	− 2	− 9	−21		
78	31	30	28	26	24	21	19	16	13	9	+ 5	− 1	− 9	−20	
79	34	32	30	28	26	24	22	19	16	13	10	+ 5	− 1	− 8	−20
80	36	34	32	30	28	26	24	22	20	17	13	10	+ 6	± 0	− 7

Temperature of Dew-point in Degrees Fahrenheit. *Continued*

Pressure = 30.0 inches of mercury

Air temp., t	Vapor press., e	Depression of wet-bulb thermometer ($t - t'$)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
80	1.022	79	77	76	74	73	72	70	68	67	65	63	62	60	58	56
81	1.056	80	78	77	75	74	73	71	70	68	66	65	63	61	59	57
82	1.091	81	79	78	77	75	74	72	71	69	67	66	64	62	60	59
83	1.127	82	80	79	78	76	75	73	72	70	69	67	65	64	62	60
84	1.163	83	81	80	79	77	76	74	73	71	70	68	66	65	63	61
85	1.201	84	82	81	80	78	77	75	74	72	71	69	68	66	64	62
86	1.241	85	83	82	81	79	78	76	75	73	72	70	69	67	65	64
87	1.281	86	84	83	82	80	79	78	76	75	73	72	70	68	67	65
88	1.322	87	85	84	83	81	80	79	77	76	74	73	71	69	68	66
89	1.364	88	86	85	84	82	81	80	78	77	75	74	72	71	69	67
90	1.408	89	87	86	85	83	82	81	79	78	76	75	73	72	70	69
91	1.453	90	88	87	86	85	83	82	80	79	78	76	75	73	71	70
92	1.499	91	89	88	87	86	84	83	81	80	79	77	76	74	73	71
93	1.546	92	90	89	88	87	85	84	83	81	80	78	77	75	74	72
94	1.595	93	92	90	89	88	86	85	84	82	81	79	78	76	75	73
95	1.645	94	93	91	90	89	87	86	85	83	82	80	79	78	76	74
96	1.696	95	94	92	91	90	88	87	86	84	83	82	80	79	77	76
97	1.749	96	95	93	92	91	89	88	87	85	84	83	81	80	78	77
98	1.803	97	96	94	93	92	90	89	88	87	85	84	82	81	79	78
99	1.859	98	97	95	94	93	92	90	89	88	86	85	83	82	81	79
100	1.916	99	98	96	95	94	93	91	90	89	87	86	85	83	82	80
101	1.975	100	99	97	96	95	94	92	91	90	88	87	86	84	83	81
102	2.035	101	100	98	97	96	95	93	92	91	89	88	87	85	84	83
103	2.097	102	101	99	98	97	96	94	93	92	91	89	88	86	85	84
104	2.160	103	102	100	99	98	97	95	94	93	92	90	89	88	86	85
105	2.225	104	103	101	100	99	98	96	95	94	93	91	90	89	87	86
106	2.292	105	104	102	101	100	99	98	96	95	94	92	91	90	88	87
107	2.360	106	105	103	102	101	100	99	97	96	95	93	92	91	90	88
108	2.431	107	106	104	103	102	101	100	98	97	96	95	93	92	91	89
109	2.503	108	107	105	104	103	102	101	99	98	97	96	94	93	92	90
110	2.576	109	108	106	105	104	103	102	100	99	98	97	95	94	93	91
111	2.652	110	109	108	106	105	104	103	102	100	99	98	96	95	94	93
112	2.730	111	110	109	107	106	105	104	103	101	100	99	98	96	95	94
113	2.810	112	111	110	108	107	106	105	104	102	101	100	99	97	96	95
114	2.891	113	112	111	109	108	107	106	105	103	102	101	100	98	97	96
115	2.975	114	113	112	110	109	108	107	106	104	103	102	101	99	98	97
116	3.061	115	114	113	111	110	109	108	107	105	104	103	102	101	99	98
117	3.148	116	115	114	112	111	110	109	108	107	105	104	103	102	100	99
118	3.239	117	116	115	113	112	111	110	109	108	106	105	104	103	101	100
119	3.331	118	117	116	114	113	112	111	110	109	107	106	105	104	102	101
120	3.425	119	118	117	115	114	113	112	111	110	108	107	106	105	104	102
121	3.522	120	119	118	116	115	114	113	112	111	109	108	107	106	105	103
122	3.621	121	120	119	118	116	115	114	113	112	110	109	108	107	106	104
123	3.723	122	121	120	119	117	116	115	114	113	112	110	109	108	107	106
124	3.827	123	122	121	120	118	117	116	115	114	113	111	110	109	108	107
125	3.933	124	123	122	121	119	118	117	116	115	114	112	111	110	109	108
126	4.042	125	124	123	122	120	119	118	117	116	115	113	112	111	110	109
127	4.154	126	125	124	123	121	120	119	118	117	116	114	113	112	111	110
128	4.268	127	126	125	124	122	121	120	119	118	117	116	114	113	112	111
129	4.385	128	127	126	125	123	122	121	120	119	118	117	115	114	113	112
130	4.504	129	128	127	126	124	123	122	121	120	119	118	116	115	114	113
131	4.627	130	129	128	127	125	124	123	122	121	120	119	117	116	115	114
132	4.752	131	130	129	128	126	125	124	123	122	121	120	119	117	116	115
133	4.880	132	131	130	129	127	126	125	124	123	122	121	120	118	117	116
134	5.011	133	132	131	130	129	127	126	125	124	123	122	121	119	118	117
135	5.145	134	133	132	131	130	128	127	126	125	124	123	122	120	119	118
136	5.282	135	134	133	132	131	129	128	127	126	125	124	123	122	120	119
137	5.422	136	135	134	133	132	130	129	128	127	126	125	124	123	121	120
138	5.565	137	136	135	134	133	131	130	129	128	127	126	125	124	122	121
139	5.712	138	137	136	135	134	132	131	130	129	128	127	126	125	123	122
140	5.862	139	138	137	136	135	133	132	131	130	129	128	127	126	124	123

Temperature of Dew-point in Degrees Fahrenheit. *Continued*

Pressure = 30.0 inches of mercury

Air temp., t	Vapor press., e	Depression of wet-bulb thermometer $(t - t')$														
		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
80	1.022	54	52	50	47	44	42	39	36	32	28	24	20	13	6	−7
81	1.056	55	53	51	49	46	43	41	38	34	31	27	22	17	10	+7
82	1.091	57	55	52	50	48	45	42	39	36	33	29	25	20	14	+7
83	1.127	58	56	54	52	49	47	44	41	38	35	31	27	23	18	11
84	1.163	59	57	55	53	51	48	46	43	40	37	34	30	26	21	15
85	1.201	61	59	57	54	52	50	48	45	42	39	36	32	28	24	19
86	1.241	62	60	58	56	54	52	49	47	44	41	38	34	31	27	22
87	1.281	63	61	59	57	55	53	51	48	46	43	40	36	33	29	25
88	1.322	64	62	61	59	57	55	52	50	47	45	42	38	35	31	27
89	1.364	66	64	62	60	58	56	54	51	49	46	44	41	37	34	30
90	1.408	67	65	63	61	59	57	55	53	51	48	45	43	39	36	32
91	1.453	68	66	65	63	61	59	57	55	52	50	47	44	41	38	35
92	1.499	69	68	66	64	62	60	58	56	54	51	49	46	43	40	37
93	1.546	71	69	67	65	63	62	60	58	55	53	51	48	45	42	39
94	1.595	72	70	68	67	65	63	61	59	57	55	52	50	47	44	41
95	1.645	73	71	70	68	66	64	62	60	58	56	54	52	49	46	43
96	1.696	74	72	71	69	67	66	64	62	60	58	55	53	51	48	45
97	1.749	75	74	72	70	69	67	65	63	61	59	57	55	52	50	47
98	1.803	76	75	73	72	70	68	66	64	63	61	58	56	54	52	49
99	1.859	78	76	74	73	71	69	68	66	64	62	60	58	56	53	51
100	1.916	79	77	76	74	72	71	69	67	65	63	61	59	57	55	52
101	1.975	80	78	77	75	74	72	70	69	67	65	63	61	59	56	54
102	2.035	81	80	78	76	75	73	72	70	68	66	64	62	60	58	56
103	2.097	82	81	79	78	76	74	73	71	69	68	66	64	62	60	57
104	2.160	83	82	80	79	77	76	74	72	71	69	67	65	63	61	59
105	2.225	84	83	82	80	78	77	75	74	72	70	68	67	65	63	61
106	2.292	86	84	83	81	80	78	77	75	73	72	70	68	66	64	62
107	2.360	87	85	84	82	81	79	78	76	75	73	71	69	67	66	64
108	2.431	88	86	85	84	82	81	79	77	76	74	72	71	69	67	65
109	2.503	89	88	86	85	83	82	80	79	77	75	74	72	70	68	66
110	2.576	90	89	87	86	84	83	81	80	78	77	75	73	72	70	68
111	2.652	91	90	88	87	86	84	83	81	80	78	76	75	73	71	69
112	2.730	92	91	90	88	87	85	84	82	81	79	78	76	74	72	71
113	2.810	93	92	91	89	88	86	85	84	82	80	79	77	76	74	72
114	2.891	94	93	92	90	89	88	86	85	83	82	80	79	77	75	73
115	2.975	96	94	93	92	90	89	87	86	84	83	81	80	78	76	75
116	3.061	97	95	94	93	91	90	88	87	86	84	83	81	79	78	76
117	3.148	98	96	95	94	92	91	90	88	87	85	84	82	81	79	77
118	3.239	99	98	96	95	94	92	91	89	88	86	85	84	82	80	79
119	3.331	100	99	97	96	95	93	92	91	89	88	86	85	83	82	80
120	3.425	101	100	98	97	96	94	93	92	90	89	87	86	84	83	81
121	3.522	102	101	100	98	97	96	94	93	91	90	89	87	86	84	83
122	3.621	103	102	101	99	98	97	95	94	93	91	90	88	87	85	84
123	3.723	104	103	102	100	99	98	96	95	94	92	91	90	88	87	85
124	3.827	105	104	103	102	100	99	98	96	95	94	92	91	89	88	86
125	3.933	106	105	104	103	101	100	99	97	96	95	93	92	90	89	88
126	4.042	107	106	105	104	102	101	100	99	97	96	94	93	92	90	89
127	4.154	109	107	106	105	104	102	101	100	98	97	96	94	93	91	90
128	4.268	110	108	107	106	105	103	102	101	99	98	97	95	94	93	91
129	4.385	111	109	108	107	106	104	103	102	101	99	98	97	95	94	92
130	4.504	112	110	109	108	107	106	104	103	102	100	99	98	96	95	94
131	4.627	113	112	110	109	108	107	105	104	103	101	100	99	97	96	95
132	4.752	114	113	111	110	109	108	106	105	104	103	101	100	99	97	96
133	4.880	115	114	112	111	110	109	108	106	105	104	102	101	100	98	97
134	5.011	116	115	114	112	111	110	109	107	106	105	104	102	101	100	98
135	5.145	117	116	115	113	112	111	110	108	107	106	105	103	102	101	99
136	5.282	118	117	116	114	113	112	111	110	108	107	106	104	103	102	101
137	5.422	119	118	117	116	114	113	112	111	109	108	107	106	104	103	102
138	5.565	120	119	118	117	115	114	113	112	110	109	108	107	105	104	103
139	5.712	121	120	119	118	116	115	114	113	112	110	109	108	107	105	104
140	5.862	122	121	120	119	117	116	115	114	113	111	110	109	108	106	105

Temperature of Dew-point in Degrees Fahrenheit.
Continued
Pressure = 30.0 inches of mercury

Air temp., t	Vapor press., e	Depression of wet-bulb thermometer $(t - t')$														
		31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
80	1.022	−53														
81	1.056	−18														
82	1.091	− 6	−43													
83	1.127	+ 2	−15													
84	1.163	8	− 4	−33												
85	1.201	12	+ 3	−12												
86	1.241	16	9	− 2	−27											
87	1.281	20	13	+ 5	−10											
88	1.322	23	17	10	± 0	−22										
89	1.364	26	21	15	+ 6	− 7										
90	1.408	28	24	19	11	+ 1	−17									
91	1.453	31	27	22	16	8	− 4	−40								
92	1.499	33	29	25	20	13	+ 4	−13								
93	1.546	36	32	28	23	17	10	− 2	−28							
94	1.595	38	34	30	26	21	14	+ 6	− 9							
95	1.645	40	37	33	29	24	19	11	+ 1	−20						
96	1.696	42	39	35	31	27	22	16	8	− 5						
97	1.749	44	41	38	34	30	25	20	13	+ 3	−15					
98	1.803	46	43	40	36	32	28	23	17	10	− 2	−33				
99	1.859	48	45	42	39	35	31	26	21	15	+ 6	−10				
100	1.916	50	47	44	41	37	33	29	25	19	12	+ 1	−22			
101	1.975	52	49	46	43	40	36	32	28	23	17	8	− 5			
102	2.035	53	51	48	45	42	38	35	31	26	21	14	+ 4	−14		
103	2.097	55	53	50	47	44	41	37	33	29	24	18	11	− 2	−32	
104	2.160	57	54	52	49	46	43	40	36	32	27	22	16	+ 7	− 9	
105	2.225	58	56	54	51	48	45	42	38	34	30	26	20	13	+ 2	−20
106	2.292	60	58	55	53	50	47	44	41	37	33	29	24	18	9	− 4
107	2.360	62	59	57	55	52	49	46	43	40	36	32	27	22	15	+ 5
108	2.431	63	61	59	56	54	51	48	45	42	39	35	30	25	20	12
109	2.503	64	62	60	58	56	53	50	47	44	41	37	33	29	23	17
110	2.576	66	64	62	60	57	55	52	50	47	43	40	36	32	27	21
111	2.652	67	65	63	61	59	57	54	52	49	46	42	39	35	30	25
112	2.730	69	67	65	63	61	58	56	54	51	48	45	41	37	33	29
113	2.810	70	68	66	64	62	60	58	55	53	50	47	44	40	36	32
114	2.891	72	70	68	66	64	62	59	57	55	52	49	46	43	39	35
115	2.975	73	71	69	67	65	63	61	59	56	54	51	48	45	42	38
116	3.061	74	73	71	69	67	65	63	60	58	56	53	50	47	44	40
117	3.148	76	74	72	70	68	66	64	62	60	58	55	52	49	46	43
118	3.239	77	75	74	72	70	68	66	64	62	59	57	54	51	49	45
119	3.331	78	77	75	73	71	69	67	65	63	61	59	56	53	51	48
120	3.425	80	78	76	75	73	71	69	67	65	63	60	58	55	53	50
121	3.522	81	79	78	76	74	72	70	68	66	64	62	60	57	55	52
122	3.621	82	81	79	77	76	74	72	70	68	66	64	62	59	57	54
123	3.723	84	82	80	79	77	75	73	71	69	67	65	63	61	58	56
124	3.827	85	83	82	80	78	77	75	73	71	69	67	65	63	60	58
125	3.933	86	84	83	81	80	78	76	74	72	71	69	66	64	62	60
126	4.042	87	86	84	83	81	79	78	76	74	72	70	68	66	64	62
127	4.154	88	87	85	84	82	81	79	77	75	74	72	70	68	65	63
128	4.268	90	88	87	85	84	82	80	79	77	75	73	71	69	67	65
129	4.385	91	89	88	86	85	83	82	80	78	76	75	73	71	69	67
130	4.504	92	91	89	88	86	85	83	81	80	78	76	74	72	70	68
131	4.627	93	92	90	89	87	86	84	83	81	79	77	76	74	72	70
132	4.752	94	93	92	90	89	87	86	84	82	81	79	77	75	73	71
133	4.880	96	94	93	91	90	88	87	85	84	82	80	78	77	75	73
134	5.011	97	95	94	93	91	90	88	87	85	83	82	80	78	76	74
135	5.145	98	97	95	94	92	91	89	88	86	85	83	81	80	78	76
136	5.282	99	98	96	95	94	92	91	89	88	86	84	83	81	79	77
137	5.422	100	99	98	96	95	93	92	90	89	87	86	84	82	81	79
138	5.565	101	100	99	97	96	95	93	92	90	89	87	85	84	82	80
139	5.712	103	101	100	99	97	96	94	93	91	90	88	87	85	83	82
140	5.862	104	102	101	100	98	97	96	94	93	91	90	88	86	85	83

Temperature of Dew-point in Degrees Fahrenheit. *Continued*

Pressure = 30.0 inches of mercury

Air temp., t	Depression of wet-bulb thermometer ($t - t'$)														
	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
106	−56														
107	−12														
108	± 0	−26													
109	+ 8	− 6													
110	14	+ 4	−16												
111	19	11	− 1	−35											
112	23	17	+ 8	− 8											
113	27	21	14	+ 3	−19										
114	30	25	19	11	− 2	−50									
115	33	29	23	16	+ 7	−10									
116	36	32	27	21	14	+ 2	−22								
117	39	35	30	25	19	10	− 3								
118	42	38	34	29	23	16	+ 7	−11							
119	44	41	37	32	27	21	14	+ 2	−25						
120	47	43	39	35	30	25	19	10	− 4						
121	49	46	42	38	34	29	23	16	+ 6	−12					
122	51	48	45	41	37	32	27	21	14	+ 1	−27				
123	53	50	47	44	40	36	31	25	19	10	− 4				
124	55	52	49	46	43	39	34	29	24	17	+ 7	−13			
125	57	54	52	49	45	42	37	33	28	22	14	+ 2	−29		
126	59	56	54	51	48	44	40	36	31	26	19	11	− 4		
127	61	58	56	53	50	47	43	39	35	30	24	17	+ 7	−13	
128	63	60	58	55	52	49	46	42	38	33	28	22	14	+ 2	−27
129	64	62	60	57	54	51	48	45	41	37	32	26	20	11	− 4
130	66	64	62	59	56	54	51	47	44	40	35	30	25	17	+ 7
131	68	66	63	61	58	56	53	50	46	43	39	34	29	23	15
132	69	67	65	63	60	58	55	52	49	45	42	37	32	27	21
133	71	69	67	64	62	60	57	54	51	48	44	40	36	31	25
134	73	71	68	66	64	62	59	56	53	50	47	43	39	34	29
135	74	72	70	68	66	63	61	58	56	53	50	46	42	38	33
136	76	74	72	70	67	65	63	60	58	55	52	49	45	41	37
137	77	75	73	71	69	67	65	62	60	57	54	51	48	44	40
138	78	77	75	73	71	69	66	64	62	59	56	53	50	47	43
139	80	78	76	74	72	70	68	66	64	61	58	56	53	50	46
140	81	80	78	76	74	72	70	68	65	63	60	58	55	52	49

Temperature of Dew-point in Degrees Fahrenheit. *Continued*

Pressure = 23.0 inches of mercury

Air temp., t	Vapor press., e	Depression of wet-bulb thermometer (t - t') 0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0
-40	0.0039	-49														
-39	41	-48														
-38	44	-46	-59													
-37	46	-45	-57													
-36	48	-43	-55													
-35	0.0051	-42	-52													
-34	54	-40	-50													
-33	57	-39	-48													
-32	61	-38	-46	-59												
-31	65	-36	-44	-55												
-30	0.0069	-34	-42	-52												
-29	74	-33	-40	-49												
-28	78	-32	-38	-46	-60											
-27	83	-30	-36	-44	-55											
-26	89	-29	-34	-41	-51											
-25	0.0094	-28	-32	-39	-48											
-24	0.0100	-27	-31	-36	-45	-57										
-23	106	-26	-30	-34	-42	-51										
-22	112	-25	-29	-33	-39	-47										
-21	119	-24	-27	-31	-36	-44	-57									
-20	0.0126	-23	-26	-29	-34	-40	-51									
-19	133	-22	-24	-28	-32	-37	-47									
-18	141	-20	-23	-26	-30	-35	-43	-54								
-17	150	-19	-22	-25	-28	-32	-39	-48								
-16	159	-18	-20	-23	-26	-30	-35	-43	-57							
-15	0.0168	-17	-19	-22	-25	-28	-33	-39	-49							
-14	178	-16	-18	-20	-23	-26	-30	-36	-44	-57						
-13	188	-15	-17	-19	-22	-25	-28	-33	-39	-49						
-12	199	-14	-16	-18	-20	-23	-26	-30	-35	-43	-56					
-11	210	-13	-14	-16	-19	-21	-24	-28	-32	-39	-48					
-10	0.0222	-12	-13	-15	-17	-20	-22	-26	-29	-34	-42	-55				
-9	234	-11	-12	-14	-16	-18	-21	-24	-27	-31	-37	-46				
-8	247	-10	-11	-13	-15	-17	-19	-22	-25	-29	-33	-40	-50			
-7	260	-8	-10	-12	-14	-15	-17	-20	-23	-26	-30	-35	-44	-56		
-6	275	-7	-9	-10	-12	-14	-16	-18	-21	-24	-27	-32	-38	-47		
-5	0.0291	-6	-8	-9	-11	-12	-14	-16	-19	-22	-25	-29	-33	-40	-51	
-4	307	-5	-6	-8	-10	-11	-13	-15	-17	-19	-22	-26	-30	-35	-43	-57
-3	325	-4	-5	-7	-8	-10	-11	-13	-15	-17	-20	-23	-26	-31	-37	-46
-2	344	-3	-4	-6	-7	-8	-10	-12	-14	-16	-18	-20	-23	-27	-32	-38
-1	363	-2	-3	-4	-6	-7	-8	-10	-12	-14	-16	-18	-21	-24	-28	-32
0	0.0383	-1	-2	-3	-4	-6	-7	-9	-10	-12	-14	-16	-18	-21	-24	-28
+1	403	±0	-1	-2	-3	-4	-6	-7	-9	-10	-12	-14	-16	-19	-22	-25
2	423	+1	±0	-1	-2	-3	-4	-6	-7	-9	-10	-12	-14	-16	-19	-22
3	444	2	+1	±0	-1	-2	-3	-4	-6	-7	-9	-10	-12	-14	-16	-19
4	467	3	2	+1	±0	-1	-2	-3	-5	-6	-7	-9	-10	-12	-14	-16
5	0.0491	4	3	2	+1	±0	-1	-2	-3	-5	-6	-7	-9	-10	-12	-14
6	515	5	4	3	2	+1	±0	-1	-2	-3	-4	-6	-7	-9	-10	-12
7	542	6	5	4	3	2	+1	±0	-1	-2	-3	-4	-5	-7	-9	-10
8	570	7	6	6	5	4	3	+2	+1	-1	-2	-3	-4	-5	-7	-8
9	600	8	7	7	6	5	4	3	2	+1	±0	-1	-3	-4	-5	-7
10	0.0631	9	9	8	7	6	5	4	3	2	+1	±0	-1	-2	-4	-5
11	665	10	10	9	8	7	6	5	5	4	3	+1	±0	-1	-2	-3
12	699	11	11	10	9	8	8	7	6	5	4	3	+2	+1	±0	-2
13	735	12	12	11	10	10	9	8	7	6	5	4	3	2	+1	±0
14	772	13	13	12	11	11	10	9	8	8	7	6	5	4	3	+2
15	0.0810	14	14	13	12	12	11	10	10	9	8	7	6	5	4	3
16	850	15	15	14	13	13	12	11	11	10	9	8	8	7	6	5
17	891	16	16	15	14	14	13	13	12	11	10	10	9	8	7	6
18	933	17	17	16	16	15	14	14	13	12	12	11	10	9	8	8
19	0.0979	18	18	17	17	16	15	15	14	13	13	12	11	11	10	9
20	0.1026	19	19	18	18	17	16	16	15	15	14	13	12	12	11	10

t	e	t	e	(t - t') 0.1	0.2	0.3	0.4	0.5
-60	0.0010	-52	0.0018	-60				
-59	11	-51	19	-59				
-58	12	-50	0.0021	-58				
-57	13	-49	22	-56				
-56	13	-48	24	-54				
-55	0.0015	-47	26	-53				
-54	16	-46	27	-51	-59			
-53	0.0017	-45	0.0029	-50	-57			
		-44	31	-49	-55			
		-43	33	-47	-53			
		-42	35	-46	-51	-60		
		-41	37	-45	-50	-58		
		-40	0.0039	-44	-49	-56		
		-39	41	-43	-48	-54		
		-38	44	-42	-46	-52	-59	
		-37	46	-41	-45	-50	-57	
		-36	48	-40	-43	-49	-55	
		-35	0.0051	-39	-42	-47	-52	
		-34	54	-37	-40	-45	-50	-58
		-33	57	-36	-39	-43	-48	-55
		-32	61	-35	-38	-42	-46	-52
		-31	65	-33	-36	-40	-44	-49
		-30	0.0069	-32	-34	-38	-42	-47

Temperature of Dew-point in Degrees Fahrenheit
Continued
Pressure = 23.0 inches of mercury

Air temp., t	Depression of wet-bulb thermometer $(t - t')$														
	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0	5.2	5.4	5.6	5.8	6.0
−2	−49														
−1	−40	−51													
0	−33	−41	−52												
+1	−29	−33	−42	−54											
2	−25	−29	−34	−43	−56										
3	−22	−25	−29	−34	−43	−58									
4	−19	−22	−25	−29	−35	−44	−59								
5	−17	−19	−22	−25	−29	−35	−45	−60							
6	−14	−17	−19	−22	−25	−30	−35	−45	−60						
7	−12	−14	−16	−19	−22	−25	−30	−35	−45						
8	−10	−12	−14	−16	−19	−22	−25	−29	−35	−45					
9	− 8	−10	−12	−14	−16	−19	−21	−25	−29	−35	−44	−60			
10	− 6	− 8	−10	−12	−14	−16	−18	−21	−24	−29	−34	−43	−59		
11	− 5	− 6	− 7	− 9	−11	−13	−15	−18	−20	−24	−28	−33	−42	−56	
12	− 3	− 4	− 5	− 7	− 9	−11	−13	−15	−17	−20	−23	−27	−32	−40	−53
13	− 1	− 2	− 4	− 5	− 7	− 8	−10	−12	−14	−17	−19	−22	−26	−31	−38
14	± 0	− 1	− 2	− 3	− 5	− 6	− 8	− 9	−11	−13	−16	−18	−21	−25	−29
15	+ 2	+ 1	± 0	− 1	− 3	− 4	− 5	− 7	− 9	−11	−13	−15	−17	−20	−24
16	4	3	+ 2	± 0	− 1	− 2	− 3	− 5	− 6	− 8	−10	−12	−14	−16	−19
17	5	4	3	+ 2	+ 1	± 0	− 2	− 3	− 4	− 5	− 7	− 9	−11	−13	−15
18	7	6	5	4	3	+ 2	± 0	− 1	− 2	− 3	− 5	− 6	− 8	−10	−12
19	8	7	6	5	4	3	+ 2	+ 1	± 0	− 1	− 3	− 4	− 5	− 7	− 9
20	9	9	8	7	6	5	4	3	+ 2	+ 1	− 1	− 2	− 3	− 5	− 6

t	$(t - t')$									
	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.6	7.8	8.0
13	−49									
14	−36	−47								
15	−28	−34	−44	−59						
16	−22	−27	−32	−40	−53					
17	−18	−21	−25	−29	−36	−47				
18	−14	−17	−20	−23	−27	−33	−42	−58		
19	−11	−13	−16	−18	−21	−25	−30	−37	−49	
20	− 8	−10	−12	−14	−17	−20	−23	−28	−33	−44

Temperature of Dew-point in Degrees Fahrenheit. *Continued*

Pressure 23.0 inches of mercury

Air temp., t	Vapor press., e	Depression of wet-bulb thermometer $(t - t')$															
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
20	0.103	19	17	16	14	12	10	8	6	3	1	−3	−6	−11	−17	−26	−44
21	0.108	20	18	17	15	13	12	10	8	5	2	−1	−4	−8	−13	−20	−30
22	0.113	21	19	18	16	15	13	11	9	7	4	+1	−2	−5	−10	−15	−23
23	0.118	22	20	19	17	16	14	12	10	8	6	3	±0	−3	−7	−12	−18
24	0.124	23	21	20	19	17	15	14	12	10	8	5	+2	−1	−4	−8	−14
25	0.130	24	23	21	20	18	17	15	13	11	9	7	4	+1	−2	−5	−10
26	0.136	25	24	22	21	20	18	16	15	13	11	9	6	4	+1	−3	−7
27	0.143	26	25	23	22	21	19	18	16	14	12	10	8	6	3	±0	−4
28	0.150	27	26	24	23	22	20	19	17	16	14	12	10	8	5	+2	−1
29	0.157	28	27	26	24	23	22	20	19	17	15	13	11	9	7	4	+1
30	0.164	29	28	27	25	24	23	21	20	18	17	15	13	11	9	7	4
31	0.172	30	29	28	27	25	24	23	21	20	18	17	15	13	11	8	6
32	0.180	31	30	29	28	26	25	24	23	21	20	18	16	14	12	10	8
33	0.187	32	31	30	29	28	26	25	24	22	21	19	18	16	14	12	10
34	0.195	33	32	31	30	29	28	26	25	24	22	21	19	18	16	14	12
35	0.203	34	33	32	31	30	29	28	26	25	24	22	21	19	17	16	14
36	0.211	35	34	33	32	31	30	29	27	26	25	24	22	21	19	17	15
37	0.219	36	35	34	33	32	31	30	28	27	26	25	24	22	20	19	17
38	0.228	37	36	35	34	33	32	31	30	28	27	26	25	23	22	20	19
39	0.237	38	37	36	35	34	33	32	31	30	28	27	26	25	23	22	20
40	0.247	39	38	37	36	35	34	33	32	31	30	28	27	26	25	23	22
41	0.256	40	39	38	37	36	35	34	33	32	31	29	28	27	26	24	23
42	0.266	41	40	39	38	37	36	35	34	33	32	31	29	28	27	26	24
43	0.277	42	41	40	39	38	37	36	35	34	33	32	31	29	28	27	26
44	0.287	43	42	41	40	39	38	37	36	35	34	33	32	31	29	28	27
45	0.298	44	43	42	41	40	39	38	37	36	35	34	33	32	31	29	28
46	0.310	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30
47	0.322	46	45	44	43	42	42	41	40	38	37	36	35	34	33	32	31
48	0.334	47	46	45	44	44	43	42	41	40	39	38	37	35	34	33	32
49	0.347	48	47	46	46	45	44	43	42	41	40	39	38	37	36	34	33
50	0.360	49	48	47	47	46	45	44	43	42	41	40	39	38	37	36	34
51	0.373	50	49	48	48	47	46	45	44	43	42	41	40	39	38	37	36
52	0.387	51	50	50	49	48	47	46	45	44	43	42	41	40	39	38	37
53	0.402	52	51	51	50	49	48	47	46	45	44	43	42	41	40	39	38
54	0.417	53	52	52	51	50	49	48	47	46	45	44	44	43	42	41	40
55	0.432	54	53	53	52	51	50	49	48	48	47	46	45	44	43	42	41
56	0.448	55	54	54	53	52	51	50	49	49	48	47	46	45	44	43	42
57	0.465	56	56	55	54	53	52	51	50	50	49	48	47	46	45	44	43
58	0.482	57	57	56	55	54	53	52	52	51	50	49	48	47	46	45	44
59	0.499	58	58	57	56	55	54	54	53	52	51	50	49	48	47	46	46
60	0.517	59	59	58	57	56	55	55	54	53	52	51	50	49	49	48	47
61	0.536	60	60	59	58	57	56	56	55	54	53	52	52	51	50	49	48
62	0.555	61	61	60	59	58	58	57	56	55	54	53	53	52	51	50	49
63	0.575	62	62	61	60	59	59	58	57	56	55	55	54	53	52	51	50
64	0.595	63	63	62	61	60	60	59	58	57	56	56	55	54	53	52	51
65	0.616	64	64	63	62	61	61	60	59	58	58	57	56	55	54	54	53
66	0.638	65	65	64	63	62	62	61	60	59	59	58	57	56	55	55	54
67	0.661	66	66	65	64	63	63	62	61	61	60	59	58	57	57	56	55
68	0.684	67	67	66	65	64	64	63	62	62	61	60	59	58	58	57	56
69	0.707	68	68	67	66	66	65	64	63	63	62	61	60	60	59	58	57
70	0.732	69	69	68	67	67	66	65	64	64	63	62	61	61	60	59	58
71	0.757	70	70	69	68	68	67	66	66	65	64	63	62	62	61	60	59
72	0.783	71	71	70	69	69	68	67	67	66	65	64	64	63	62	61	60
73	0.810	72	72	71	70	70	69	68	68	67	66	65	65	64	63	62	62
74	0.838	73	73	72	71	71	70	69	69	68	67	66	66	65	64	64	63
75	0.866	74	74	73	72	72	71	70	70	69	68	67	67	66	65	65	64
76	0.896	75	75	74	73	73	72	71	71	70	69	69	68	67	66	66	65
77	0.926	76	76	75	74	74	73	72	72	71	70	70	69	68	67	67	66
78	0.957	77	77	76	75	75	74	73	73	72	71	71	70	69	69	68	67
79	0.989	78	78	77	76	76	75	74	74	73	72	72	71	70	70	69	68
80	1.022	79	79	78	77	77	76	75	75	74	73	73	72	71	71	70	69

Temperature of Dew-point in Degrees Fahrenheit. *Continued*

Pressure = 23.0 inches of mercury

Air temp., t	Vapor press., e	Depression of wet-bulb thermometer $(t - t')$															
		8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0
22	0.113	−37															
23	0.118	−28	−50														
24	0.124	−21	−32														
25	0.130	−16	−24	−42													
26	0.136	−12	−18	−29	−56												
27	0.143	− 8	−14	−21	−34												
28	0.150	− 5	−10	−16	−24	−43											
29	0.157	− 2	− 6	−11	−18	−29	−57										
30	0.164	± 0	− 3	− 7	−13	−21	−33										
31	0.172	+ 3	± 0	− 4	− 9	−15	−23	−40									
32	0.180	5	+ 2	− 1	− 5	−10	−16	−26	−50								
33	0.187	8	5	+ 2	− 2	− 6	−11	−18	−30								
34	0.195	10	7	4	+ 1	− 3	− 7	−12	−20	−34							
35	0.203	12	9	7	4	± 0	− 3	− 8	−14	−22	−40						
36	0.211	13	11	9	6	+ 3	± 0	− 4	− 9	−15	−25	−47					
37	0.219	15	13	11	9	6	+ 3	− 1	− 5	−10	−17	−28	−60				
38	0.228	17	15	13	11	8	6	+ 2	− 1	− 5	−11	−18	−31				
39	0.237	19	17	15	13	11	8	5	+ 2	− 2	− 6	−12	−20	−34			
40	0.247	20	19	17	15	13	10	8	5	+ 1	− 2	− 7	−13	−22	−39		
41	0.256	22	20	19	17	15	12	10	8	5	+ 1	− 3	− 8	−14	−23	−45	
42	0.266	23	22	20	18	17	14	12	10	7	4	+ 1	− 3	− 8	−15	−25	−50
43	0.277	24	23	22	20	18	16	14	12	10	7	4	± 0	− 4	− 9	−16	−27
44	0.287	26	24	23	22	20	18	16	14	12	10	7	+ 4	± 0	− 4	−10	−17
45	0.298	27	26	24	23	21	20	18	16	14	12	10	7	+ 4	± 0	− 5	−10
46	0.310	28	27	26	24	23	21	20	18	16	14	12	10	7	+ 3	− 1	− 5
47	0.322	30	28	27	26	24	23	21	20	18	16	14	12	9	7	+ 3	− 1
48	0.334	31	30	28	27	26	24	23	21	20	18	16	14	12	9	6	+ 3
49	0.347	32	31	30	28	27	26	24	23	21	20	18	16	14	11	9	6
50	0.360	33	32	31	30	28	27	26	24	23	21	20	18	16	14	11	9
51	0.373	34	33	32	31	30	29	27	26	24	23	21	20	18	16	14	11
52	0.387	36	35	34	32	31	30	29	27	26	24	23	21	20	18	16	14
53	0.402	37	36	35	34	32	31	30	29	27	26	25	23	21	20	18	16
54	0.417	38	37	36	35	34	32	31	30	29	27	26	25	23	21	20	18
55	0.432	40	39	38	36	35	34	32	31	30	29	27	26	25	23	22	20
56	0.448	41	40	39	38	36	35	34	33	31	30	29	28	26	25	23	22
57	0.465	42	41	40	39	38	37	35	34	33	32	30	29	28	26	25	23
58	0.482	43	42	41	40	39	38	37	36	34	33	32	31	29	28	26	25
59	0.499	45	44	43	42	40	39	38	37	36	35	33	32	31	29	28	27
60	0.517	46	45	44	43	42	41	40	38	37	36	35	33	32	31	30	28
61	0.536	47	46	45	44	43	42	41	40	39	37	36	35	34	32	31	30
62	0.555	48	47	46	45	44	43	42	41	40	39	38	36	35	34	32	31
63	0.575	49	48	47	46	45	44	43	42	41	40	39	38	37	35	34	33
64	0.595	50	50	49	48	47	46	45	44	43	42	41	39	38	37	36	34
65	0.616	52	51	50	49	48	47	46	45	44	43	42	41	40	38	37	36
66	0.638	53	52	51	50	49	48	47	46	45	44	43	42	41	40	39	38
67	0.661	54	53	52	51	50	50	49	48	47	46	45	44	42	41	40	39
68	0.684	55	54	54	53	52	51	50	49	48	47	46	45	44	43	42	40
69	0.707	56	56	55	54	53	52	51	50	49	48	47	46	45	44	43	42
70	0.732	57	57	56	55	54	53	52	51	50	50	49	48	47	46	44	43
71	0.757	59	58	57	56	55	54	54	53	52	51	50	49	48	47	46	45
72	0.783	60	59	58	57	56	56	55	54	53	52	51	50	49	48	47	46
73	0.810	61	60	59	58	58	57	56	55	54	53	52	51	50	49	48	47
74	0.838	62	61	60	60	59	58	57	56	55	54	54	53	52	51	50	49
75	0.866	63	62	62	61	60	59	58	57	57	56	55	54	53	52	51	50
76	0.896	64	63	63	62	61	60	59	59	58	57	56	55	54	53	52	51
77	0.926	65	65	64	63	62	61	61	60	59	58	57	56	56	55	54	53
78	0.957	66	66	65	64	63	63	62	61	60	59	58	58	57	56	55	54
79	0.989	67	67	66	65	64	64	63	62	61	60	60	59	58	57	56	55
80	1.022	69	68	67	66	66	65	64	63	62	62	61	60	59	58	58	57

Temperature of Dew-point in Degrees Fahrenheit. *Continued*

Pressure = 23.0 inches of mercury

Air temp., t	Depression of wet-bulb thermometer (t − t')															
	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0
44	−29															
45	−18	−31														
46	−11	−19	−33													
47	− 5	−11	−20	−35												
48	− 1	− 5	−12	−20	−38											
49	+ 3	− 1	− 6	−12	−21	−40										
50	6	+ 3	− 1	− 6	−12	−21	−42									
51	9	6	+ 2	− 2	− 6	−12	−22	−44								
52	11	9	6	+ 2	− 2	− 7	−13	−22	−46							
53	14	11	9	6	+ 2	− 2	− 7	−14	−23	−47						
54	16	13	11	9	6	+ 2	− 2	− 7	−14	−24	−50					
55	18	16	14	11	8	5	+ 2	− 2	− 7	−14	−25	−55				
56	20	18	16	14	11	8	5	+ 2	− 2	− 8	−15	−26	−60			
57	22	20	18	16	14	11	8	5	+ 2	− 3	− 8	−15	−26			
58	23	22	20	18	16	14	11	9	5	+ 2	− 3	− 8	−15	−27		
59	25	24	22	20	18	16	14	11	9	5	+ 2	− 3	− 8	−16	−28	
60	27	25	24	22	20	18	16	14	11	9	6	+ 2	− 3	− 8	−16	−28
61	28	27	25	24	22	20	18	16	14	12	9	6	+ 2	− 3	− 8	−18
62	30	28	27	26	24	22	20	19	17	14	12	9	6	+ 2	− 3	− 6
63	32	30	29	27	26	24	22	21	19	17	14	12	9	6	+ 2	− 3
64	33	32	30	29	28	26	24	23	21	19	17	15	12	9	6	+ 2
65	35	33	32	31	29	28	26	25	23	21	19	17	15	12	10	6
66	36	35	34	32	31	29	28	27	25	23	22	19	17	15	13	10
67	38	36	35	34	32	31	30	28	27	25	24	22	20	18	15	13
68	39	38	37	35	34	33	31	30	28	27	25	24	22	20	18	16
69	41	39	38	37	36	34	33	32	30	29	27	26	24	22	20	18
70	42	41	40	38	37	36	35	33	32	31	29	27	26	24	22	20
71	44	42	41	40	39	38	36	35	34	32	31	29	28	26	25	23
72	45	44	43	42	40	39	38	37	35	34	32	31	29	28	27	25
73	46	45	44	43	42	41	40	38	37	36	34	33	31	30	28	27
74	48	47	46	45	43	42	41	40	38	37	36	34	33	32	30	29
75	49	48	47	46	45	44	43	42	40	39	38	36	35	34	32	31
76	50	49	48	47	46	45	44	43	42	41	39	38	37	35	34	32
77	52	51	50	49	48	47	46	44	43	42	41	40	38	37	36	34
78	53	52	51	50	49	48	47	46	45	44	43	41	40	39	37	36
79	54	54	53	52	51	50	49	47	46	45	44	43	42	40	39	38
80	56	55	54	53	52	51	50	49	48	47	46	44	43	42	41	40

t	Depression of wet-bulb thermometer (t − t')															
	24.5	25.0	25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0	31.5	32.0
61	−29															
62	−16	−29														
63	− 8	−16	−28													
64	− 2	− 7	−15	−28												
65	+ 2	− 2	− 7	−15	−28											
66	7	+ 3	− 2	− 7	−15	−27										
67	10	7	+ 3	− 1	− 7	−14	−27									
68	13	10	7	+ 3	− 1	− 6	−14	−26								
69	16	13	11	8	+ 4	− 1	− 6	−13	−25							
70	18	16	14	11	8	+ 4	± 0	− 5	−13	−24						
71	21	19	17	14	11	8	+ 5	± 0	− 5	−12	−23	−54				
72	23	21	19	17	14	12	9	+ 5	+ 1	− 4	−11	−22	−50			
73	25	23	22	20	17	15	12	9	6	+ 1	− 4	−11	−20	−45		
74	27	26	24	22	20	18	15	12	10	6	+ 2	− 3	−10	−19	−41	
75	29	28	26	24	22	20	18	15	13	10	7	+ 2	− 3	− 9	−18	−37
76	31	29	28	26	24	23	21	18	16	13	10	7	+ 3	− 2	− 8	−17
77	33	31	30	28	27	25	23	21	19	16	14	11	8	+ 4	− 1	− 7
78	35	33	32	30	29	27	25	23	21	19	17	14	11	8	+ 4	± 0
79	37	35	33	32	31	29	27	26	24	22	20	17	15	12	9	+ 5
80	38	37	35	34	32	31	29	28	26	24	22	20	18	15	12	9

t	(t − t')				
	32.5	33.0	33.5	34.0	34.5
76	−33				
77	−15	−30			
78	− 6	−14	−28		
79	± 0	− 5	−13	−26	
80	+ 6	+ 1	− 4	−11	−23

TEMPERATURE OF DEW-POINT IN DEGREES FAHRENHEIT. *Continued*

Pressure = 23.0 inches of mercury

Air temp., t	Vapor press., e	Depression of wet-bulb thermometer ($t - t'$)															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
80	1.022	79	77	76	75	73	72	71	69	68	66	65	63	62	60	58	57
81	1.056	80	78	77	76	75	73	72	70	69	67	66	64	63	61	60	58
82	1.091	81	79	78	77	76	74	73	71	70	69	67	66	64	62	61	59
83	1.127	82	81	79	78	77	75	74	72	71	70	68	67	65	64	62	60
84	1.163	83	82	80	79	78	76	75	74	72	71	69	68	66	65	63	62
85	1.201	84	83	81	80	79	77	76	75	73	72	70	69	67	66	64	63
86	1.241	85	84	82	81	80	78	77	76	74	73	72	70	69	67	66	64
87	1.281	86	85	83	82	81	79	78	77	75	74	73	71	70	68	67	65
88	1.322	87	86	84	83	82	80	79	78	76	75	74	72	71	69	68	66
89	1.364	88	87	85	84	83	82	80	79	78	76	75	73	72	71	69	67
90	1.408	89	88	86	85	84	83	81	80	79	77	76	75	73	72	70	69
91	1.453	90	89	87	86	85	84	82	81	80	78	77	76	74	73	71	70
92	1.499	91	90	88	87	86	85	83	82	81	79	78	77	75	74	72	71
93	1.546	92	91	89	88	87	86	84	83	82	81	79	78	76	75	74	72
94	1.595	93	92	90	89	88	87	85	84	83	82	80	79	78	76	75	73
95	1.645	94	93	91	90	89	88	87	85	84	83	81	80	79	77	76	74
96	1.696	95	94	92	91	90	89	88	86	85	84	82	81	80	78	77	76
97	1.749	96	95	93	92	91	90	89	87	86	85	83	82	81	79	78	77
98	1.803	97	96	94	93	92	91	90	88	87	86	85	83	82	81	79	78
99	1.859	98	97	95	94	93	92	91	89	88	87	86	84	83	82	80	79
100	1.916	99	98	96	95	94	93	92	90	89	88	87	85	84	83	81	80
101	1.975	100	99	98	96	95	94	93	92	90	89	88	86	85	84	83	81
102	2.035	101	100	99	97	96	95	94	93	91	90	89	88	86	85	84	82
103	2.097	102	101	100	98	97	96	95	94	92	91	90	89	87	86	85	83
104	2.160	103	102	101	99	98	97	96	95	93	92	91	90	88	87	86	85
105	2.225	104	103	102	100	99	98	97	96	94	93	92	91	89	88	87	86
106	2.292	105	104	103	101	100	99	98	97	95	94	93	92	91	89	88	87
107	2.360	106	105	104	102	101	100	99	98	97	95	94	93	92	90	89	88
108	2.431	107	106	105	103	102	101	100	99	98	96	95	94	93	91	90	89
109	2.503	108	107	106	104	103	102	101	100	99	97	96	95	94	92	91	90
110	2.576	109	108	107	105	104	103	102	101	100	98	97	96	95	94	92	91
111	2.652	110	109	108	106	105	104	103	102	101	99	98	97	96	95	93	92
112	2.730	111	110	109	108	106	105	104	103	102	101	99	98	97	96	94	93
113	2.810	112	111	110	109	107	106	105	104	103	102	100	99	98	97	96	94
114	2.891	113	112	111	110	108	107	106	105	104	103	101	100	99	98	97	95
115	2.975	114	113	112	111	109	108	107	106	105	104	102	101	100	99	98	96
116	3.061	115	114	113	112	110	109	108	107	106	105	103	102	101	100	99	97
117	3.148	116	115	114	113	111	110	109	108	107	106	105	103	102	101	100	99
118	3.239	117	116	115	114	112	111	110	109	108	107	106	104	103	102	101	100
119	3.331	118	117	116	115	113	112	111	110	109	108	107	105	104	103	102	101
120	3.425	119	118	117	116	114	113	112	111	110	109	108	106	105	104	103	102
121	3.522	120	119	118	117	115	114	113	112	111	110	109	108	106	105	104	103
122	3.621	121	120	119	118	116	115	114	113	112	111	110	109	107	106	105	104
123	3.723	122	121	120	119	118	116	115	114	113	112	111	110	108	107	106	105
124	3.827	123	122	121	120	119	117	116	115	114	113	112	111	109	108	107	106
125	3.933	124	123	122	121	120	118	117	116	115	114	113	112	111	109	108	107
126	4.042	125	124	123	122	121	119	118	117	116	115	114	113	112	110	109	108
127	4.154	126	125	124	123	122	120	119	118	117	116	115	114	113	111	110	109
128	4.268	127	126	125	124	123	121	120	119	118	117	116	115	114	112	111	110
129	4.385	128	127	126	125	124	122	121	120	119	118	117	116	115	114	112	111
130	4.504	129	128	127	126	125	123	122	121	120	119	118	117	116	115	113	112
131	4.627	130	129	128	127	126	124	123	122	121	120	119	118	117	116	114	113
132	4.752	131	130	129	128	127	126	124	123	122	121	120	119	118	117	115	114
133	4.880	132	131	130	129	128	127	125	124	123	122	121	120	119	118	117	115
134	5.011	133	132	131	130	129	128	126	125	124	123	122	121	120	119	118	116
135	5.145	134	133	132	131	130	129	127	126	125	124	123	122	121	120	119	117
136	5.282	135	134	133	132	131	130	128	127	126	125	124	123	122	121	120	118
137	5.422	136	135	134	133	132	131	129	128	127	126	125	124	123	122	121	120
138	5.565	137	136	135	134	133	132	130	129	128	127	126	125	124	123	122	121
139	5.712	138	137	136	135	134	133	132	130	129	128	127	126	125	124	123	122
140	5.862	139	138	137	136	135	134	133	131	130	129	128	127	126	125	124	123

Temperature of Dew-point in Degrees Fahrenheit. *Continued*

Pressure = 23.0 inches of mercury

Air temp., t	Vapor press., e	Depression of wet-bulb thermometer (t − t′)															
		17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
80	1.022	55	53	51	49	47	44	42	40	37	34	31	28	24	20	15	9
81	1.056	56	54	52	50	48	46	44	41	39	36	33	30	27	23	18	13
82	1.091	57	56	54	52	50	47	45	43	40	38	35	32	29	25	21	16
83	1.127	59	57	55	53	51	49	47	44	42	40	37	34	31	27	24	19
84	1.163	60	58	56	54	52	50	48	46	44	41	39	36	32	29	26	22
85	1.201	61	59	58	56	54	52	50	48	45	43	40	38	35	31	28	25
86	1.241	62	61	59	57	55	53	51	49	47	45	42	40	37	34	30	27
87	1.281	64	62	60	58	57	55	53	51	48	46	44	41	39	36	32	29
88	1.322	65	63	61	60	58	56	54	52	50	48	46	43	40	38	35	31
89	1.364	66	64	63	61	59	57	55	54	52	49	47	45	42	39	37	33
90	1.408	67	66	64	62	60	59	57	55	53	51	49	46	44	41	38	35
91	1.453	68	67	65	63	62	60	58	56	54	52	50	48	46	43	40	37
92	1.499	69	68	66	65	63	61	59	58	56	54	52	50	47	45	42	39
93	1.546	71	69	68	66	64	63	61	59	57	55	53	51	49	46	44	42
94	1.595	72	70	69	67	66	64	62	60	59	57	55	53	50	48	46	43
95	1.645	73	72	70	68	67	65	63	62	60	58	56	54	52	50	48	45
96	1.696	74	73	71	70	68	66	65	63	61	60	58	56	54	51	49	47
97	1.749	75	74	72	71	69	68	66	64	63	61	59	57	55	53	51	48
98	1.803	76	75	74	72	70	69	67	66	64	62	60	58	56	54	52	50
99	1.859	78	76	75	73	72	70	69	67	65	64	62	60	58	56	54	52
100	1.916	79	77	76	74	73	71	70	68	67	65	63	61	59	58	56	53
101	1.975	80	78	77	76	74	73	71	69	68	66	64	63	61	59	57	55
102	2.035	81	80	78	77	75	74	72	71	69	67	66	64	62	60	58	56
103	2.097	82	81	79	78	76	75	73	73	70	69	67	65	64	62	60	58
104	2.160	83	82	80	79	78	76	75	73	72	70	68	67	65	63	61	59
105	2.225	84	83	82	80	79	77	76	74	73	71	70	68	66	64	63	61
106	2.292	85	84	83	81	80	78	77	76	74	72	71	69	68	66	64	62
107	2.360	86	85	84	82	81	80	78	77	75	74	72	71	69	67	66	64
108	2.431	88	86	85	84	82	81	79	78	76	75	73	72	70	69	67	65
109	2.503	89	87	86	85	83	82	81	79	78	76	75	73	72	70	68	66
110	2.576	90	88	87	86	84	83	82	80	79	77	76	74	73	71	69	68
111	2.652	91	90	88	87	86	84	83	81	80	79	77	76	74	72	71	69
112	2.730	92	91	89	88	87	85	84	83	81	80	78	77	75	74	72	70
113	2.810	93	92	90	89	88	87	85	84	82	81	80	78	76	75	73	72
114	2.891	94	93	92	90	89	88	86	85	84	82	81	79	78	76	75	73
115	2.975	95	94	93	91	90	89	87	86	85	83	82	80	79	77	76	74
116	3.061	96	95	94	92	91	90	89	87	86	84	83	82	80	79	77	76
117	3.148	97	96	95	94	92	91	90	88	87	86	84	83	81	80	78	77
118	3.239	98	97	96	95	93	92	91	89	88	87	85	84	83	81	80	78
119	3.331	99	98	97	96	94	93	92	90	89	88	87	85	84	82	81	79
120	3.425	101	99	98	97	96	94	93	92	90	89	88	86	85	84	82	81
121	3.522	102	100	99	98	97	95	94	93	92	90	89	88	86	85	83	82
122	3.621	103	101	100	99	98	96	95	94	93	91	90	89	87	86	84	83
123	3.723	104	102	101	100	99	98	96	95	94	92	91	90	88	87	86	84
124	3.827	105	104	102	101	100	99	97	96	95	94	92	91	90	88	87	85
125	3.933	106	105	103	102	101	100	99	97	96	95	93	92	91	89	88	87
126	4.042	107	106	104	103	102	101	100	98	97	96	95	93	92	91	89	88
127	4.154	108	107	106	104	103	102	101	99	98	97	96	94	93	92	90	89
128	4.268	109	108	107	105	104	103	102	101	99	98	97	95	94	93	92	90
129	4.385	110	109	108	106	105	104	103	102	100	99	98	97	95	94	93	91
130	4.504	111	110	109	108	106	105	104	130	101	100	99	98	96	95	94	92
131	4.627	112	111	110	109	107	106	105	104	103	101	100	99	98	96	95	94
132	4.752	113	112	111	110	108	107	106	105	104	102	101	100	99	97	96	95
133	4.880	114	113	112	111	110	108	107	106	105	104	102	101	100	99	97	96
134	5.011	115	114	113	112	111	109	108	107	106	105	103	102	101	100	98	97
135	5.145	116	115	114	113	112	111	109	108	107	106	104	103	102	101	99	98
136	5.282	117	116	115	114	113	112	110	109	108	107	106	104	103	102	101	99
137	5.422	118	117	116	115	114	113	111	110	109	108	107	105	104	103	102	100
138	5.565	119	118	117	116	115	114	112	111	110	109	108	107	105	104	103	102
139	5.712	120	119	118	117	116	115	114	112	111	110	109	108	106	105	104	103
140	5.862	121	120	119	118	117	116	115	113	112	111	110	109	108	106	105	104

TEMPERATURE OF DEW-POINT IN DEGREES FAHRENHEIT. *Concluded*

Pressure 23.0 inches of mercury

Air temp., t	Vapor press., e	Depression of wet-bulb thermometer $(t - t')$ 33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
80	1.022	1	−11														
81	1.056	6	− 3	−21													
82	1.091	11	+ 3	− 9	−41												
83	1.127	14	8	− 1	−17												
84	1.163	18	12	+ 5	− 6	−30											
85	1.201	21	16	9	+ 1	−13											
86	1.241	23	19	13	6	− 4	−23										
87	1.281	26	22	17	11	+ 3	−10	−54									
88	1.322	28	24	20	15	8	− 1	−18									
89	1.364	30	27	23	18	12	+ 5	− 7	−34								
90	1.408	32	29	25	21	16	10	+ 1	−14								
91	1.453	34	31	28	24	20	14	7	− 3	−25							
92	1.499	36	33	30	27	23	18	11	+ 3	− 9	−59						
93	1.546	39	36	32	29	25	21	15	9	− 1	−17						
94	1.595	41	38	35	31	28	24	19	13	+ 6	− 5	−32					
95	1.645	42	40	37	33	30	26	22	17	11	+ 2	−12					
96	1.696	44	42	39	36	32	29	25	20	15	8	− 2	−22				
97	1.749	46	44	41	38	34	31	28	23	19	13	+ 5	− 7	−41			
98	1.803	48	45	43	40	37	33	30	26	22	17	10	+ 1	−15			
99	1.859	50	47	45	42	39	36	32	29	25	21	14	7	− 3	−28		
100	1.916	51	49	46	44	41	38	35	31	28	24	19	12	+ 4	− 9		
101	1.975	53	51	48	46	43	40	37	34	30	26	22	17	10	± 0	−18	
102	2.035	54	52	50	48	45	42	39	36	32	29	25	20	14	+ 7	− 5	−32
103	2.097	56	54	52	49	47	44	41	38	35	31	28	23	18	12	+ 3	−11
104	2.160	57	55	53	51	49	46	43	40	37	34	30	26	22	16	9	− 1
105	2.225	59	57	55	53	50	48	45	42	39	36	33	29	25	20	14	+ 6
106	2.292	60	58	56	54	52	50	47	44	42	39	35	32	28	24	18	12
107	2.360	62	60	58	56	54	51	49	46	44	41	38	34	31	27	22	16
108	2.431	63	61	59	57	55	53	51	48	46	43	40	37	33	29	25	20
109	2.503	65	63	61	59	57	55	53	50	48	45	42	39	36	32	28	24
110	2.576	66	64	62	60	58	56	54	52	50	47	44	41	38	34	31	27
111	2.652	67	66	64	62	60	58	56	54	51	49	46	43	40	37	33	30
112	2.730	69	67	65	63	62	60	57	55	53	51	48	46	43	40	36	32
113	2.810	70	68	67	65	63	61	59	57	55	52	50	48	45	42	38	35
114	2.891	71	70	68	66	64	63	61	59	56	54	52	49	47	44	41	38
115	2.975	73	71	69	68	66	64	62	60	58	56	54	51	49	46	43	40
116	3.061	74	72	71	69	67	66	64	62	60	58	55	53	50	48	45	42
117	3.148	75	74	72	70	69	67	65	63	61	59	57	55	52	50	47	44
118	3.239	77	75	73	72	70	68	67	65	63	61	59	57	54	52	49	47
119	3.331	78	76	75	73	71	70	68	66	64	62	60	58	56	54	51	49
120	3.425	79	78	76	74	73	71	69	68	66	64	62	60	58	55	53	50
121	3.522	80	79	77	76	74	72	71	69	67	65	63	61	59	57	55	52
122	3.621	82	80	79	77	75	74	72	70	69	67	65	63	61	59	57	54
123	3.723	83	81	80	78	77	75	74	72	70	68	66	64	63	61	58	56
124	3.827	84	83	81	80	78	76	75	73	72	70	68	66	64	62	60	58
125	3.933	85	84	82	81	79	78	76	74	73	71	69	68	66	64	62	60
126	4.042	86	85	84	82	81	79	78	76	74	72	71	69	67	65	63	61
127	4.154	88	86	85	83	82	80	79	77	76	74	72	70	69	67	65	63
128	4.268	89	87	86	85	83	82	80	78	77	75	74	72	70	68	66	
129	4.385	90	89	87	86	84	83	81	80	78	77	75	73	72	70	68	66
130	4.504	91	90	88	87	86	84	83	81	80	78	76	75	73	71	69	68
131	4.627	92	91	90	88	87	85	84	82	81	79	78	76	74	72	71	69
132	4.752	93	92	91	89	88	87	85	84	82	81	79	77	76	74	72	70
133	4.880	95	93	92	91	89	88	86	85	83	82	80	79	77	75	74	72
134	5.011	96	94	93	92	90	89	88	86	85	83	82	80	78	77	75	73
135	5.145	97	96	94	93	92	90	89	87	86	84	83	81	80	78	76	75
136	5.282	98	97	95	94	93	91	90	89	87	86	84	83	81	80	78	76
137	5.422	99	98	97	95	94	93	91	90	88	87	85	84	82	81	79	78
138	5.565	100	99	98	96	95	94	92	91	90	88	87	85	84	82	81	79
139	5.712	101	100	99	98	96	95	94	92	91	89	88	86	85	83	82	80
140	5.862	103	101	100	99	97	96	95	93	92	91	89	88	86	85	83	81

	$(t - t')$ 49	50	51	52	53
104	−20				
105	− 6	−40			
106	+ 3	−12			
107	9	−1	−23		
108	14	−6	− 6	−49	
109	19	12	+3	−14	
110	22	17	9	− 2	−25

Relative Humidity, Per Cent.—Fahrenheit Temperatures

Pressure 30.0 inches of mercury

Air temp., t	Depression of wet-bulb thermometer $(t - t')$																			
	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0
−40	46																			
−39	48																			
−38	50	2																		
−37	53	6																		
−36	56	10																		
−35	59	15																		
−34	61	20																		
−33	63	24																		
−32	64	28																		
−31	66	32	0																	
−30	68	36	4																	
−29	70	41	9																	
−28	72	45	15																	
−27	74	48	19																	
−26	75	51	24	0																
−25	76	53	29	5																
−24	77	55	32	10																
−23	78	57	36	15																
−22	80	59	39	20	0															
−21	81	61	43	24	5															
−20	82	63	45	28	10															
−19	83	65	48	32	15															
−18	84	67	51	35	19	2														
−17	85	69	53	39	23	7														
−16	86	70	56	42	27	12														
−15	86	72	58	45	31	17	4													
−14	87	74	61	48	34	21	8													
−13	88	75	63	50	38	25	13	0												
−12	88	76	64	52	41	29	17	6												
−11	89	77	66	55	44	32	21	10												
−10	90	78	68	57	46	36	25	14	4											
− 9	90	79	70	59	49	39	29	18	9											
− 8	90	81	71	61	51	42	32	22	13	3										
− 7	91	82	72	63	54	44	35	26	17	8										
− 6	91	82	73	64	56	47	38	29	20	12	3									
− 5	91	83	75	66	58	49	41	32	24	16	7									
− 4	92	84	76	68	60	52	44	36	28	20	12	4								
− 3	92	85	77	69	61	54	46	39	31	23	16	8	1							
− 2	92	85	78	71	63	56	49	42	34	27	19	12	5							
− 1	93	86	79	72	65	58	51	44	37	30	23	16	10	3						
0	93	87	80	73	67	60	53	47	40	33	27	20	14	7	1					
+ 1	93	87	81	75	68	62	56	49	43	36	30	24	18	11	5					
2	94	88	82	76	70	64	58	52	46	39	33	27	21	15	9	3				
3	94	88	82	77	71	65	59	54	48	42	36	30	25	19	13	7	2			
4	94	89	83	78	72	66	61	55	50	44	39	33	28	22	17	11	6	0		
5	95	89	84	78	73	68	63	57	52	46	41	36	31	25	20	15	10	4		
6	95	90	84	79	74	69	64	59	54	49	43	38	33	28	23	18	13	8	3	
7	95	90	85	80	75	70	65	60	55	51	46	41	36	31	26	21	17	12	7	2
8	95	90	86	81	76	71	67	62	57	53	48	43	38	34	29	24	20	15	11	6
9	95	91	86	82	77	72	68	63	59	55	50	46	41	36	32	27	23	18	14	10
10	96	91	87	82	78	73	69	65	60	56	52	47	43	39	34	30	26	22	17	13
11	96	91	87	83	79	74	70	66	62	58	53	49	45	41	37	33	28	25	20	16
12	96	92	88	84	80	75	71	67	63	59	55	51	47	43	39	35	31	27	23	19
13	96	92	88	84	80	76	73	69	65	61	57	53	49	45	41	38	34	30	26	23
14	96	92	89	85	81	77	74	70	66	62	59	55	51	48	44	40	37	33	29	26
15	96	93	89	86	82	78	75	71	67	64	60	57	53	50	46	42	39	35	32	29
16	96	93	90	86	82	79	76	72	69	65	62	58	55	51	48	45	41	38	34	31
17	97	93	90	86	83	80	77	73	70	66	63	60	57	53	50	47	43	40	37	34
18	97	93	90	87	84	80	77	74	71	68	65	61	58	55	52	49	45	42	39	36
19	97	94	90	87	84	81	78	75	72	69	66	63	60	56	53	50	47	44	41	38
20	97	94	91	88	85	82	79	76	73	70	67	64	61	58	55	52	49	46	43	40

	$(t - t')$									
	4.2	4.4	4.6	4.8	5.0	5.2	5.4	5.6	5.8	6.0
8	1									
9	5	1								
10	9	5	0							
11	12	8	4	0						
12	16	12	8	4	0					
13	19	15	11	7	4	0				
14	22	18	15	11	8	4	0			
15	25	21	18	14	11	7	4	0		
16	28	24	21	18	14	11	8	4	1	
17	30	27	24	21	17	14	11	8	5	1
18	33	30	27	24	20	17	14	11	8	5
19	35	32	29	26	23	20	17	14	11	8
20	37	34	32	29	26	23	20	17	14	12

	$(t - t')$				
	0.1	0.2	0.3	0.4	0.5
−50	50				
−49	54	5			
−48	57	12			
−47	60	17			
−46	63	22			
−45	66	28			
−44	68	32			
−43	70	36	3		
−42	71	40	9		
−41	72	43	14		
−40	73	46	18		
−39	74	48	22		
−38	75	50	25	2	
−37	76	53	28	6	
−36	77	56	33	10	
−35	78	59	37	15	
−34	80	61	41	20	0
−33	81	63	44	24	5
−32	82	64	46	28	10
−31	83	66	49	32	15
−30	84	68	52	36	20

ATIVE HUMIDITY, PER CENT.—FAHRENHEIT TEMPERATURES.
Continued
Pressure = 30.0 inches of mercury

	Depression of wet-bulb thermometer ($t - t'$)																			
5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5
2	85	77	70	62	55	48	40	33	26	19	12	5								
2	85	78	71	63	56	49	42	35	28	21	15	8	1							
3	86	78	71	65	58	51	44	37	31	24	17	11	4							
3	86	79	72	66	59	52	46	39	33	26	20	14	7	1						
3	87	80	73	67	60	54	47	41	35	29	22	16	10	4						
4	87	81	74	68	62	55	49	43	37	31	25	19	13	7	1					
4	87	81	75	69	63	57	51	45	39	33	27	21	16	10	4					
4	88	82	76	70	64	58	52	47	41	35	29	24	18	13	7	2				
4	88	82	76	71	65	59	54	48	43	37	32	26	21	15	10	5				
4	88	83	77	72	66	60	55	50	44	39	34	28	23	18	13	8	3			
4	89	83	78	73	67	62	56	51	46	41	36	31	26	21	16	11	6	1		
4	89	84	78	73	68	63	58	52	47	42	37	33	28	23	18	13	8	4		
5	89	84	79	74	69	64	59	54	49	44	39	35	30	25	20	16	11	7	2	
5	90	85	80	75	70	65	60	56	51	46	41	37	32	27	23	18	14	9	5	0
5	90	86	81	76	71	66	62	57	52	48	43	38	34	29	25	21	16	12	8	3
5	91	86	81	77	72	67	63	58	54	49	45	40	36	32	27	23	19	14	10	6
5	91	86	82	77	73	68	64	60	55	51	46	42	38	34	29	25	21	17	13	9
5	91	87	83	78	74	69	65	61	57	53	48	44	40	36	31	27	23	19	15	11
6	91	87	83	79	75	70	66	62	58	54	50	46	42	37	33	29	25	21	17	14
6	92	87	83	79	75	71	67	63	59	55	51	47	43	39	35	31	27	24	20	16
6	92	87	83	79	75	71	68	64	60	56	52	48	45	41	37	33	29	26	22	18
6	92	88	84	80	76	72	69	65	61	57	54	50	46	42	39	35	31	28	24	20
6	92	88	85	81	77	73	69	65	62	58	55	51	47	44	40	36	33	30	26	23
6	92	88	85	81	77	73	70	66	63	59	55	52	48	45	42	38	35	31	28	25
6	93	89	85	81	78	74	71	67	63	60	56	53	49	46	43	39	36	33	30	26
6	93	89	86	82	78	74	71	67	64	61	57	54	51	47	44	41	38	34	31	28
6	93	89	86	82	79	75	72	68	65	61	58	55	52	48	45	42	39	35	32	29
6	93	89	86	82	79	75	72	69	66	62	59	56	53	49	46	43	40	37	34	31
6	93	90	86	83	79	76	73	69	66	63	60	57	54	50	47	44	41	38	35	32
6	93	90	86	83	80	76	73	70	67	64	61	57	54	51	48	45	42	39	46	34
6	93	90	87	83	80	77	74	71	67	64	61	58	55	52	49	46	43	41	38	35
7	94	90	87	84	81	78	75	71	68	65	62	59	56	53	50	47	45	42	39	36
7	94	90	87	84	81	78	75	72	69	66	63	60	57	54	51	49	46	43	40	37
7	94	90	87	84	81	78	75	72	69	66	63	61	58	55	52	50	47	44	41	39
7	94	91	88	85	82	79	76	73	70	67	64	61	59	56	53	50	48	45	42	40
7	94	91	88	85	82	79	76	73	70	68	65	62	59	57	54	51	49	46	43	41
7	94	91	88	85	82	79	76	73	71	68	65	63	60	57	55	52	50	47	44	42
7	94	91	88	85	82	80	77	74	71	69	66	63	61	58	55	53	50	48	45	43
7	94	91	88	85	83	80	77	74	72	69	66	64	61	59	56	54	51	49	46	44
7	94	91	89	86	83	80	78	75	72	70	67	65	62	59	57	55	52	49	47	45
7	94	91	89	86	83	81	78	75	73	70	68	65	63	60	58	55	53	50	48	46
7	94	92	89	86	84	81	78	76	73	71	68	65	63	61	58	56	54	51	49	47
7	94	92	89	86	84	81	79	76	74	71	69	66	64	61	59	57	54	52	50	47
7	95	92	89	87	84	82	79	77	74	71	69	67	64	62	60	57	55	53	50	48
7	95	92	90	87	84	82	79	77	74	72	70	67	65	63	60	58	56	53	51	49
7	95	92	90	87	85	82	80	77	75	72	70	68	66	63	61	59	56	54	52	50
7	95	92	90	87	85	82	80	78	75	73	71	68	66	64	61	59	57	55	53	51
7	95	92	90	87	85	83	80	78	75	73	71	69	66	64	62	60	58	56	53	51
7	95	92	90	88	85	83	80	78	76	74	71	69	67	65	62	60	58	56	54	52
7	95	93	90	88	85	83	81	79	76	74	72	70	67	65	63	61	59	57	55	53
8	95	93	90	88	86	83	81	79	77	74	72	70	68	66	64	61	59	57	55	53
8	95	93	90	88	86	84	81	79	77	75	72	70	68	66	64	62	60	58	56	54
8	95	93	91	88	86	84	82	79	77	75	73	71	69	67	65	63	61	59	57	55
8	95	93	91	88	86	84	82	80	78	75	73	71	69	67	65	63	61	59	57	55
8	95	93	91	89	86	84	82	80	78	76	74	71	69	67	65	63	61	60	58	56
8	96	93	91	89	86	84	82	80	78	76	74	72	70	68	66	64	62	60	58	56
8	96	93	91	89	87	84	82	80	78	76	74	72	70	68	66	64	62	61	59	57
8	96	93	91	89	87	85	83	81	79	77	74	72	71	69	67	65	63	61	59	57
8	96	93	91	89	87	85	83	81	79	77	75	73	71	69	67	65	63	62	60	58
8	96	93	91	89	87	85	83	81	79	77	75	73	71	69	68	66	64	62	60	58
8	96	94	91	89	87	85	83	81	79	77	75	74	72	70	68	66	64	62	61	59

RELATIVE HUMIDITY, PER CENT.—FAHRENHEIT TEMPERATURE
Continued
Pressure = 30.0 inches of mercury

Air temp., t	Depression of wet-bulb thermometer (t − t′)																			
	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5
35	2																			
36	5	1																		
37	7	3																		
38	10	6	2																	
39	12	8	5	1																
40	15	11	7	4	0															
41	17	13	10	6	3															
42	19	16	12	9	5	2														
43	21	18	14	11	8	4	1													
44	23	20	16	13	10	7	4	0												
45	25	22	18	15	12	9	6	3												
46	26	23	20	17	14	11	8	5	2											
47	28	25	22	19	16	13	10	7	5	2										
48	29	26	23	21	18	15	12	9	7	4	1									
49	31	28	25	22	19	17	14	11	9	6	3	1								
50	32	29	27	24	21	18	16	13	10	8	5	3	0							
51	34	31	28	26	23	20	17	15	12	9	7	4	2							
52	35	32	29	27	24	22	19	17	14	11	9	6	4	1						
53	36	33	31	28	26	23	20	18	16	13	10	8	6	3	1					
54	37	35	32	29	27	24	22	20	17	15	12	10	8	5	3	1				
55	38	36	33	31	28	26	23	21	19	16	14	12	9	7	5	2	0			
56	39	37	34	32	30	27	25	22	20	18	16	13	11	9	7	4	2			
57	40	38	35	33	31	28	26	24	22	19	17	15	13	10	8	6	4	2		
58	41	39	37	34	32	30	27	25	23	21	18	14	14	12	10	8	6	3	2	
59	42	40	38	35	33	31	29	26	24	22	20	18	16	13	11	9	7	5	3	1
60	43	41	39	37	34	32	30	28	26	23	21	19	17	15	13	11	9	7	5	3
61	44	42	40	38	35	33	31	29	27	25	22	20	18	16	14	12	10	8	7	5
62	45	43	41	39	36	34	32	30	28	26	24	22	20	18	16	14	12	10	8	6
63	46	44	42	40	37	35	33	31	29	27	25	23	21	19	17	15	13	11	10	8
64	47	45	43	41	38	36	34	32	30	28	26	24	22	20	18	17	15	13	11	9
65	48	46	44	41	39	37	35	33	31	29	27	25	24	22	20	18	16	14	12	11
66	48	46	44	42	40	38	36	34	32	30	29	27	25	23	21	19	17	16	14	12
67	49	47	45	43	41	39	37	35	33	31	30	28	26	24	22	20	19	17	15	13
68	50	48	46	44	42	40	38	36	34	32	31	29	27	25	23	21	20	18	16	15
69	51	49	47	45	43	41	39	37	35	33	32	30	28	26	24	23	21	19	18	16
70	51	49	48	46	44	42	40	38	36	34	33	31	29	27	25	24	22	20	19	17
71	52	50	48	46	45	43	41	39	37	35	33	32	30	28	27	25	23	22	20	18
72	53	51	49	47	45	43	42	40	38	36	34	33	31	29	28	26	24	23	21	19
73	53	51	50	48	46	44	42	40	39	37	35	34	32	30	29	27	25	24	22	20
74	54	52	50	48	47	45	43	41	39	38	36	34	33	31	29	28	26	25	23	21
75	54	53	51	49	47	45	44	42	40	39	37	35	34	32	30	29	27	26	24	23
76	55	53	51	50	48	46	44	43	41	39	38	36	34	33	31	30	28	27	25	24
77	56	54	52	50	48	47	45	43	42	40	39	37	35	34	32	31	29	28	26	25
78	56	54	53	51	49	47	46	44	43	41	39	38	36	34	33	31	30	28	27	25
79	57	55	53	51	50	48	46	45	43	42	40	38	37	35	34	32	31	29	28	26
80	57	55	54	52	50	49	47	45	44	42	41	39	38	36	35	33	32	30	29	27

Relative Humidity, Per Cent.—Fahrenheit Temperatures. *Continued*

Pressure = 30.0 inches of mercury

	Depression of wet-bulb thermometer ($t - t'$)														
	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5	28.0	28.5
61	1														
62	2	1													
63	4	2	0												
64	6	4	2	0											
65	7	5	4	2	0										
66	9	7	5	3	2	0									
67	10	8	7	5	3	2									
68	11	10	8	6	5	3	1								
69	13	11	9	8	6	5	3	1							
70	14	12	11	9	8	6	4	3	1						
71	15	13	12	10	9	7	6	4	3	1					
72	16	15	13	12	10	9	7	6	4	3	1				
73	17	16	14	13	11	10	8	7	5	4	3	1			
74	18	17	15	14	13	11	10	8	7	5	4	3	1		
75	20	18	17	15	14	12	11	9	8	7	5	4	3	1	
76	21	19	18	16	15	13	12	11	9	8	6	5	4	3	1
77	22	20	19	17	16	14	13	12	10	9	8	6	5	4	3
78	23	21	20	18	17	16	14	13	11	10	9	8	6	5	4
79	23	22	21	19	18	17	15	14	13	11	10	9	7	6	5
80	24	23	22	20	19	18	16	15	14	12	11	10	9	7	6

Air temp., t	Depression of wet-bulb thermometer ($t - t'$)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
80	96	91	87	83	79	75	72	68	64	61	57	54	50	47	44
82	96	92	88	84	80	76	72	69	65	61	58	55	51	48	45
84	96	92	88	84	80	76	73	69	66	62	59	56	52	49	46
86	96	92	88	84	81	77	73	70	66	63	60	57	53	50	47
88	96	92	88	85	81	77	74	70	67	64	61	57	54	51	48
90	96	92	89	85	81	78	74	71	68	65	61	58	55	52	49
92	96	92	89	85	82	78	75	72	68	65	62	59	56	53	50
94	96	93	89	85	82	79	75	72	69	66	63	60	57	54	51
96	96	93	89	86	82	79	76	73	69	66	63	61	58	55	52
98	96	93	89	86	83	79	76	73	70	67	64	61	58	56	53
100	96	93	89	86	83	80	77	73	70	68	65	62	59	56	54
102	96	93	90	86	83	80	77	74	71	68	65	62	60	57	55
104	97	93	90	87	83	80	77	74	71	69	66	63	60	58	55
106	97	93	90	87	84	81	78	75	72	69	66	64	61	58	56
108	97	93	90	87	84	81	78	75	72	70	67	64	62	59	57
110	97	93	90	87	84	81	78	75	73	70	67	65	62	60	57
112	97	94	90	87	84	81	79	76	73	70	68	65	63	60	58
114	97	94	91	88	85	82	79	76	74	71	68	66	63	61	58
116	97	94	91	88	85	82	79	76	74	71	69	66	64	61	59
118	97	94	91	88	85	82	79	77	74	72	69	67	64	62	59
120	97	94	91	88	85	82	80	77	74	72	69	67	65	62	60
122	97	94	91	88	85	83	80	77	75	72	70	67	65	63	60
124	97	94	91	88	85	83	80	78	75	73	70	68	65	63	61
126	97	94	91	88	86	83	80	78	75	73	70	68	66	64	61
128	97	94	91	89	86	83	81	78	76	73	71	68	66	64	62
130	97	94	91	89	86	83	81	78	76	73	71	69	67	64	62
132	97	94	92	89	86	84	81	79	76	74	71	69	67	65	63
134	97	94	92	89	86	84	81	79	76	74	72	69	67	65	63
136	97	94	92	89	86	84	81	79	77	74	72	70	68	65	63
138	97	94	92	89	87	84	82	79	77	75	72	70	68	66	64
140	97	95	92	89	87	84	82	79	77	75	73	70	68	66	64

Relative Humidity, Per Cent.—Fahrenheit Temperatures.
Continued
Pressure = 30.0 inches of mercury

t	Depression of wet-bulb thermometer ($t - t'$)														
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
80	41	38	35	32	29	26	23	20	18	15	12	10	7	5	3
82	42	39	36	33	30	28	25	22	20	17	14	12	10	7	5
84	43	40	37	35	32	29	26	24	21	19	16	14	12	9	7
86	44	42	39	36	33	31	28	26	23	21	18	16	14	11	9
88	46	43	40	37	35	32	30	27	25	22	20	18	15	13	11
90	47	44	41	39	36	34	31	29	26	24	22	19	17	15	13
92	48	45	42	40	37	35	32	30	28	25	23	21	19	17	15
94	49	46	43	41	38	36	33	31	29	27	24	22	20	18	16
96	50	47	44	42	39	37	35	32	30	28	26	24	22	20	18
98	50	48	45	43	40	38	36	34	32	29	27	25	23	21	19
100	51	49	46	44	41	39	37	35	33	30	28	26	24	22	21
102	52	49	47	45	42	40	38	36	34	32	30	28	26	24	22
104	53	50	48	46	43	41	39	37	35	33	31	29	27	25	23
106	53	51	49	46	44	42	40	38	36	34	32	30	28	26	24
108	54	52	49	47	45	43	41	39	37	35	33	31	29	27	25
110	55	52	50	48	46	44	42	40	38	36	34	32	30	28	26
112	55	53	51	49	47	44	42	40	38	36	35	33	31	29	27
114	56	54	52	49	47	45	43	41	39	37	35	34	32	30	28
116	57	54	52	50	48	46	44	42	40	38	36	34	33	31	29
118	57	55	53	51	49	47	45	43	41	39	37	35	34	32	30
120	58	55	53	51	49	47	45	43	41	40	38	36	34	33	31
122	58	56	54	52	50	48	46	44	42	40	39	37	35	34	32
124	59	57	54	52	50	48	47	45	43	41	39	38	36	34	33
126	59	57	55	53	51	49	47	45	44	42	40	38	37	35	33
128	60	58	56	54	52	50	48	46	44	42	41	39	37	36	34
130	60	58	56	54	52	50	48	47	45	43	41	40	38	37	35
132	61	58	56	55	53	51	49	47	45	44	42	40	39	37	36
134	61	59	57	55	53	51	49	48	46	44	43	41	39	38	36
136	61	59	57	55	54	52	50	48	46	45	43	41	40	38	37
138	62	60	58	56	54	52	50	49	47	45	44	42	40	39	37
140	62	60	58	56	54	53	51	49	47	46	44	43	41	40	38

wet bulb are found to agree very closely, thereby showing that it has reached its lowest temperature. A minute or more is generally required to secure the correct temperature.

When the air temperature is near the freezing point it often happens that the temperature of the wet bulb will fall several degrees below freezing point, but the water will still remain in the liquid state. No error results from this, provided the minimum temperature is reached. If, however, as frequently happens, the water suddenly freezes, a large amount of heat is liberated, and the temperature of the wet bulb immediately becomes 32°. In such cases it is necessary to continue the whirling until the ice-covered bulb has reached a minimum temperature.

The psychrometer will give fairly accurate indications, even in the sunshine, yet observations so made are not without some error, and where greater accuracy is desired, the psychrometer should be whirled in the shade.

[While the above is true for refined observations, such as were necessary in Professor Marvin's work, yet for practical work I have found that a wet- and a dry-bulb thermometer, simply mounted on a board and placed in a good draft, would give accurate enough results for technical data. In this case the cloth wrapper of the wet-bulb thermometer went down into a cup of water, so that it was always wet and hence always ready for an observation.—Editor.]

Relative Humidity, Per Cent.—Fahrenheit Temperatures. *Continued*

Pressure = 30.0 inches of mercury

Air temp., t	Depression of wet-bulb thermometer ($t - t'$)														
	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
80	0														
82	2	0													
84	5	3	0												
86	7	5	3	1											
88	9	7	5	3	1										
90	11	9	7	5	3	1									
92	13	11	9	7	5	3	1								
94	14	12	10	9	7	5	3	1							
96	16	14	12	10	8	7	5	3	2	0					
98	17	15	14	12	10	8	7	5	3	2	0				
100	19	17	15	13	12	10	8	7	5	4	2	1			
102	20	18	16	15	13	11	10	8	7	5	4	2	1		
104	21	20	18	16	14	13	11	10	8	7	5	4	2	1	
106	23	21	19	17	16	14	13	11	10	8	7	5	4	3	1
108	24	22	20	19	17	16	14	12	11	10	8	7	5	4	3
110	25	23	21	20	18	17	15	14	12	11	10	8	7	6	4
112	26	24	23	21	19	18	16	15	14	12	11	9	8	7	6
114	27	25	24	22	20	19	18	16	15	13	12	11	9	8	7
116	28	26	25	23	22	20	19	17	16	14	13	12	11	9	8
118	29	27	25	24	23	21	20	18	17	16	14	13	12	11	9
120	29	28	26	25	23	22	21	19	18	17	15	14	13	12	10
122	30	29	27	26	24	23	22	20	19	18	16	15	14	13	11
124	31	30	28	27	25	24	22	21	20	18	17	16	15	14	12
126	32	30	29	27	26	25	23	22	21	19	18	17	16	15	13
128	33	31	30	28	27	25	24	23	22	20	19	18	17	16	14
130	33	32	30	29	28	26	25	24	22	21	20	19	18	16	15
132	34	33	31	30	28	27	26	24	23	22	21	20	18	17	16
134	35	33	32	30	29	28	26	25	24	23	21	20	19	18	17
136	35	34	33	31	30	28	27	26	25	23	22	21	20	19	18
138	36	35	33	32	30	29	28	27	25	24	23	22	21	20	19
140	37	35	34	32	31	30	29	27	26	25	24	23	21	20	19

t	Depression of wet-bulb thermometer ($t - t'$)														
	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
106	0														
108	2	0													
110	3	2	1												
112	4	3	2	1											
114	6	5	3	2	1										
116	7	6	5	4	2	1	0								
118	8	7	6	5	4	3	2	1							
120	9	8	7	6	5	4	3	2	1						
122	10	9	8	7	6	5	4	3	2	1	0				
124	11	10	9	8	7	6	5	4	3	2	1	0			
126	12	11	10	9	8	7	6	5	4	3	2	2	1		
128	13	12	11	10	9	8	7	6	5	4	4	3	2	1	0
130	14	13	12	11	10	9	8	7	6	5	5	4	3	2	1
132	15	14	13	12	11	10	9	8	7	6	6	5	4	3	2
134	16	15	14	13	12	11	10	9	8	7	6	6	5	4	3
136	17	16	15	14	13	12	11	10	9	8	7	6	6	5	4
138	17	16	15	14	14	13	12	11	10	9	8	7	7	6	5
140	18	17	16	15	14	13	12	12	11	10	9	8	7	7	6

Relative Humidity, Per Cent.—Fahrenheit Temperatures. *Continued*

Pressure = 23.0 inches of mercury

Air temp., t	Depression of wet-bulb thermometer (t − t')																				
	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0	4.2
−38	62	25																			
−37	64	28																			
−36	66	31																			
−35	68	35	4																		
−34	70	39	9																		
−33	72	42	14																		
−32	73	45	18																		
−31	74	48	22																		
−30	76	51	26	1																	
−29	77	54	30	6																	
−28	79	57	34	12																	
−27	80	59	37	18																	
−26	81	62	40	22	2																
−25	82	64	44	26	8																
−24	82	65	47	30	13																
−23	83	66	50	34	18	0															
−22	84	68	53	37	22	5															
−21	85	70	55	40	26	10															
−20	86	71	57	44	30	15	2														
−19	86	73	59	47	34	20	6														
−18	87	74	62	50	37	24	11														
−17	88	75	63	52	40	27	16	3													
−16	89	77	65	54	43	31	20	8													
−15	89	78	67	57	46	35	24	13	2												
−14	90	79	69	59	48	38	28	17	7												
−13	90	80	71	61	51	41	31	22	12	2											
−12	90	81	72	63	53	44	35	26	16	7											
−11	91	82	73	64	56	47	38	29	20	11	2										
−10	92	83	75	66	58	50	41	32	24	16	7										
− 9	92	84	76	68	60	52	44	36	28	20	12	4									
− 8	92	85	77	69	62	54	46	38	31	23	16	8	0								
− 7	93	85	78	70	63	56	49	41	34	27	20	12	5								
− 6	93	86	79	72	65	58	51	44	37	30	23	16	9	3							
− 5	93	86	80	73	66	59	53	46	40	33	26	20	13	7	0						
− 4	93	87	81	74	68	61	55	49	42	36	30	23	17	10	4						
− 3	94	88	82	75	69	63	57	51	45	39	33	27	21	14	9	2					
− 2	94	88	82	76	70	65	59	53	47	41	36	30	24	18	12	7	1				
− 1	94	89	83	77	72	66	61	55	50	44	39	33	28	22	16	11	6	0			
0	95	89	84	79	73	68	62	57	52	47	41	36	31	26	20	15	10	5			
+ 1	95	90	85	80	74	69	64	59	54	49	44	39	34	29	24	19	14	9	4		
2	95	90	85	81	76	71	66	61	56	51	47	42	37	32	27	22	18	13	8	3	
3	95	91	86	81	77	72	67	63	58	53	49	44	40	35	30	26	21	17	12	7	3
4	95	91	86	82	77	73	69	64	60	55	51	46	42	38	33	29	24	20	16	11	7
5	96	91	87	82	78	74	70	65	61	57	53	48	44	40	36	31	27	23	19	15	10
6	96	91	87	83	79	75	71	66	62	58	54	50	46	42	38	34	30	26	22	18	14
7	96	92	88	84	80	76	72	68	64	60	56	52	48	44	40	36	32	29	25	21	17
8	96	92	88	84	80	76	73	69	65	61	58	54	50	46	42	39	35	31	28	24	20
9	96	92	89	85	81	77	74	70	66	63	59	55	52	48	44	41	37	34	30	27	23
10	96	93	89	85	82	78	74	71	68	64	61	57	53	50	46	43	39	36	32	29	26
11	96	93	89	86	82	79	75	72	69	65	62	58	55	52	48	45	41	38	35	32	28
12	97	93	90	86	83	80	76	73	70	66	63	60	57	53	50	47	43	40	37	34	31
13	97	93	90	87	84	81	77	74	71	68	64	61	58	55	52	49	46	42	39	36	33
14	97	94	91	87	84	81	78	75	72	69	66	63	60	57	54	51	48	45	42	39	36
15	97	94	91	88	85	82	79	76	73	70	67	64	61	58	55	52	50	47	44	41	38
16	97	94	91	88	85	83	80	77	74	71	68	66	63	60	57	54	51	49	46	43	40
17	97	94	92	89	86	83	81	78	75	72	69	67	64	61	59	56	53	50	48	45	42
18	97	95	92	89	86	84	81	79	76	73	71	68	65	63	60	57	55	52	50	47	44
19	97	95	92	89	87	84	82	79	77	74	71	69	66	64	61	59	56	54	51	49	46
20	97	95	92	90	87	85	82	80	77	75	72	70	67	65	63	60	57	55	53	50	48

t	(t − t')													
	4.4	4.6	4.8	5.0	5.2	5.4	5.6	5.8	6.0	6.2	6.4	6.6	6.4	7.0
4	2													
5	6	2												
6	10	6	2											
7	13	9	6	2										
8	16	13	9	5	2									
9	19	16	12	9	5	2								
10	22	19	15	12	9	5	2							
11	25	22	18	15	12	8	5	2						
12	27	24	21	18	15	12	9	6	2					
13	30	27	24	21	18	15	12	9	6	3	0			
14	33	30	27	24	21	18	15	12	9	6	3	1		
15	35	32	30	27	24	21	18	15	12	10	7	4	1	
16	38	35	32	29	26	24	21	18	15	13	10	7	5	2
17	40	37	34	32	29	26	24	21	19	16	13	11	8	5
18	42	39	37	34	32	29	26	24	21	19	16	14	11	9
19	44	41	39	36	34	31	29	26	24	21	19	17	14	12
20	45	43	41	38	36	33	31	29	26	24	22	19	17	15

t	(t − t')				
	0.1	0.2	0.3	0.4	0.5
−47	68	36	0		
−46	70	41	4		
−45	72	45	10		
−44	74	48	19		
−43	76	51	24	0	
−42	77	54	29	5	
−41	78	57	32	10	
−40	78	59	36	16	
−39	79	61	39	21	
−38	80	62	41	25	2
−37	80	54	43	28	7
−36	81	66	48	31	13

RELATIVE HUMIDITY, PER CENT.—FAHRENHEIT TEMPERATURES. *Continued*

Pressure = 30.0 inches of mercury

Air temp., t	Depression of wet-bulb thermometer ($t - t'$)																				
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5
20	94	87	81	75	69	63	56	50	44	38	32	26	21	15	9	3					
21	94	87	81	75	69	63	57	52	46	40	34	29	23	17	12	6	1				
22	94	88	82	76	70	64	59	53	47	42	36	31	25	20	15	9	4				
23	94	88	82	77	71	65	60	54	49	43	38	33	28	22	17	12	7	2			
24	94	89	83	78	72	67	61	56	50	45	40	35	30	25	20	15	10	5			
25	95	89	84	78	73	68	62	57	52	47	42	37	32	27	22	17	12	8	3		
26	95	89	84	79	73	68	63	58	53	48	43	38	34	29	24	19	15	10	6	1	
27	95	90	84	79	74	69	64	59	55	50	45	40	35	31	26	22	17	13	8	4	
28	95	90	85	80	75	70	65	60	56	51	46	42	37	33	28	24	19	15	11	6	2
29	95	90	85	80	76	71	66	62	57	52	48	43	39	35	30	26	22	17	13	9	5
30	95	90	86	81	76	72	67	63	58	54	49	45	41	36	32	28	24	20	16	11	7
31	95	91	86	81	77	72	68	64	59	55	51	46	42	38	34	30	26	22	18	14	10
32	95	91	86	82	77	73	69	65	60	56	52	48	44	40	36	32	28	24	20	16	12
33	96	92	87	83	78	74	70	66	62	57	53	49	45	41	38	34	30	26	22	18	15
34	96	92	88	84	79	75	71	67	63	59	55	51	47	43	39	35	32	28	24	21	17
35	96	92	88	84	80	76	72	68	64	60	56	52	49	45	41	37	34	30	26	23	19
36	96	92	88	84	80	77	73	69	65	61	58	54	50	46	43	39	35	32	28	25	21
37	96	93	89	85	81	78	74	70	66	63	59	55	52	48	44	41	37	34	30	27	23
38	96	93	89	85	81	78	74	71	67	64	60	57	53	49	46	42	39	36	32	29	25
39	96	93	89	85	81	78	75	71	68	65	61	57	54	51	48	44	41	37	34	31	27
40	96	93	89	85	82	79	75	72	68	65	62	58	55	52	49	45	42	39	36	32	29
41	96	93	89	86	82	79	76	72	69	66	62	59	56	53	50	47	44	41	37	34	31
42	96	93	89	86	83	80	76	73	70	67	63	60	57	54	51	48	45	42	39	36	33
43	96	93	90	87	83	80	77	73	70	67	64	61	58	55	52	49	46	43	40	37	34
44	97	94	90	87	83	80	77	74	71	68	65	62	59	56	53	50	47	44	41	39	36
45	97	94	90	87	84	81	78	74	71	68	65	62	60	57	54	51	48	45	42	40	37
46	97	94	90	87	84	81	78	75	72	69	66	63	60	57	55	52	49	46	44	41	38
47	97	94	90	87	84	81	78	75	72	70	67	64	61	58	55	53	50	47	45	42	39
48	97	94	91	88	85	82	79	76	73	70	67	65	62	59	56	54	51	48	46	43	40
49	97	94	91	88	85	82	79	76	73	71	68	65	62	60	57	54	52	49	47	44	41
50	97	94	91	88	85	82	79	77	74	71	68	66	63	60	57	55	52	50	48	45	42
51	97	94	91	88	86	83	80	77	75	72	69	66	64	61	58	56	53	51	49	46	43
52	97	94	91	89	86	83	80	78	75	72	70	67	64	61	59	57	54	52	49	47	44
53	97	94	91	89	86	83	80	78	75	72	70	67	65	62	60	57	55	52	50	48	45
54	97	94	92	89	86	83	81	78	76	73	70	68	65	63	60	58	56	53	51	48	46
55	97	95	92	89	86	84	81	78	76	73	71	69	66	63	61	59	56	54	52	49	47
56	97	95	92	89	87	84	81	79	76	74	71	69	67	64	62	59	57	55	52	50	48
57	97	95	92	89	87	84	82	79	77	74	72	69	67	65	62	60	57	55	53	51	49
58	97	95	92	89	87	84	82	79	77	74	72	70	67	65	63	61	58	56	54	52	50
59	97	95	92	90	87	85	82	80	77	75	73	70	68	65	63	61	59	57	55	53	50
60	97	95	92	90	87	85	82	80	78	75	73	71	68	66	64	62	59	57	55	53	51
61	97	95	92	90	88	85	83	80	78	76	73	71	69	67	64	62	60	58	56	54	52
62	97	95	92	90	88	85	83	81	78	76	74	72	69	67	65	63	61	59	56	54	52
63	97	95	93	90	88	85	83	81	79	76	74	72	70	67	65	63	61	59	57	55	53
64	97	95	93	90	88	86	83	81	79	77	74	72	70	68	66	64	62	60	58	56	54
65	98	95	93	91	88	86	84	81	79	77	75	73	71	69	66	64	62	60	58	56	54
66	98	95	93	91	88	86	84	82	79	77	75	73	71	69	67	65	63	61	59	57	55
67	98	95	93	91	89	86	84	82	80	77	75	73	71	69	67	65	63	61	59	57	55
68	98	95	93	91	89	86	84	82	80	78	76	74	72	70	68	66	64	62	60	58	56
69	98	96	93	91	89	87	84	82	80	78	76	74	72	70	68	66	64	62	60	58	57
70	98	96	93	91	89	87	85	83	80	78	76	74	72	70	68	66	64	63	61	59	57
71	98	96	93	91	89	87	85	83	81	79	77	75	73	71	69	67	65	63	61	59	58
72	98	96	93	91	89	87	85	83	81	79	77	75	73	71	69	67	65	64	62	60	58
73	98	96	93	91	89	87	85	83	81	79	77	75	73	71	70	68	66	64	62	60	59
74	98	96	94	91	89	87	85	83	81	79	77	75	74	72	70	68	66	64	63	61	59
75	98	96	94	91	89	87	85	83	81	80	78	76	74	72	70	68	66	65	63	61	60
76	98	96	94	92	90	88	86	84	82	80	78	76	74	72	70	69	67	65	63	62	60
77	98	96	94	92	90	88	86	84	82	80	78	76	74	72	71	69	67	66	64	62	60
78	98	96	94	92	90	88	86	84	82	80	78	76	75	73	71	69	68	66	64	62	61
79	98	96	94	92	90	88	86	84	82	80	78	77	75	73	71	70	68	66	65	63	61
80	98	96	94	92	90	88	86	84	82	80	79	77	75	73	72	70	68	67	65	63	62

Relative Humidity, Per Cent.—Fahrenheit Temperatures. *Continued*

Pressure = 23.0 inches of mercury

Air temp., t	Depression of wet-bulb thermometer ($t - t'$)																				
	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0
29	1																				
30	4																				
31	6	2																			
32	9	5	1																		
33	11	7	4	0																	
34	13	10	6	3																	
35	16	12	9	5	2																
36	18	15	11	8	4	1															
37	20	17	13	10	7	4	0														
38	22	19	16	12	9	6	3														
39	24	21	18	15	12	8	5	2													
40	26	23	20	17	14	11	8	5	2												
41	28	25	22	19	16	13	10	7	4	1											
42	30	27	24	21	18	15	12	9	6	3	1										
43	31	28	26	23	20	17	14	11	8	6	3	0									
44	33	30	27	25	22	19	16	13	11	8	5	3	0								
45	34	31	28	26	24	21	18	15	13	10	7	5	2								
46	35	33	30	27	25	22	20	17	15	12	9	7	4	2							
47	37	34	31	29	26	24	21	19	17	14	11	9	6	4	2						
48	38	35	32	30	28	25	23	21	18	16	13	11	9	6	4	1					
49	39	37	34	31	29	27	24	22	20	17	15	13	10	8	6	3	1				
50	40	38	35	33	30	28	26	23	21	19	17	14	12	10	8	5	3	1			
51	41	39	36	34	32	29	27	25	23	20	18	16	14	12	9	7	5	3	1		
52	42	40	37	35	33	31	28	26	24	22	20	17	15	13	11	9	7	5	3	1	
53	43	41	38	36	34	32	29	27	25	23	21	19	17	15	13	11	9	7	5	3	1
54	44	42	39	37	35	33	31	29	26	24	22	20	18	16	14	12	10	8	6	4	2
55	45	43	40	38	36	34	32	30	28	26	24	22	20	18	16	14	12	10	8	6	4
56	46	44	41	39	37	35	33	31	29	27	25	23	21	19	17	15	13	11	9	7	6
57	47	44	42	40	38	36	34	32	30	28	26	24	22	20	18	16	14	13	11	9	7
58	48	45	43	41	39	37	35	33	31	29	27	25	23	21	20	18	16	14	12	10	9
59	48	46	44	42	40	38	36	34	32	30	28	26	24	22	21	19	17	15	14	12	10
60	49	47	45	43	41	39	37	35	33	31	29	27	26	24	22	20	18	16	15	13	11
61	50	48	46	44	42	40	38	36	34	32	30	29	27	25	23	21	20	18	16	14	13
62	50	48	46	45	43	41	39	37	35	33	31	30	28	26	24	23	21	19	17	16	14
63	51	49	47	45	43	41	40	38	36	34	32	31	29	27	25	24	22	20	19	17	15
64	52	50	48	46	44	42	40	39	37	35	33	32	30	28	26	25	23	21	20	18	16
65	52	50	49	47	45	43	41	39	38	36	34	32	31	29	27	26	24	22	21	19	18
66	53	51	49	47	46	44	42	40	38	37	35	33	32	30	28	27	25	24	22	20	19
67	54	52	50	48	46	44	43	41	39	37	36	34	33	31	29	28	26	25	23	21	20
68	54	52	50	49	47	45	44	42	40	38	37	35	33	32	30	29	27	25	24	22	21
69	55	53	51	49	48	46	44	42	41	39	37	36	34	33	31	30	28	26	25	23	22
70	55	53	52	50	48	47	45	43	42	40	38	37	35	33	32	30	29	27	26	24	23
71	56	54	52	51	49	47	46	44	42	41	39	37	36	34	33	31	30	28	27	25	24
72	56	55	53	51	50	48	46	45	43	41	40	38	37	35	34	32	31	29	28	26	25
73	57	55	53	52	50	48	47	45	44	42	40	39	37	36	34	33	31	30	29	27	26
74	57	56	54	52	51	49	47	46	44	43	41	39	38	37	35	34	32	31	29	28	27
75	58	56	55	53	51	50	48	46	45	43	42	40	39	37	36	34	33	32	30	29	27
76	58	57	55	53	52	50	49	47	45	44	42	41	39	38	37	35	34	32	31	29	28
77	59	57	55	54	52	51	49	48	46	44	43	41	40	39	37	36	34	33	32	30	29
78	59	57	56	54	53	51	50	48	47	45	44	42	41	39	38	36	35	34	32	31	29
79	60	58	56	55	53	52	50	49	47	46	44	43	41	40	39	37	36	34	33	32	30
80	60	58	57	55	54	52	51	49	48	46	45	43	42	41	39	38	37	35	34	33	31

RELATIVE HUMIDITY, PER CENT.—FAHRENHEIT TEMPERATURES.
Continued
Pressure = 23.0 inches of mercury

t	$(t - t')$												
	22	23	24	25	26	27	28	29	30	31	32	33	34
60	8	5	1										
61	9	6	3										
62	11	8	4	1									
63	12	9	6	3									
64	13	10	7	4	1								
65	15	12	9	6	3								
66	16	13	10	7	4	1							
67	17	14	11	8	5	3							
68	18	15	12	9	7	4	1						
69	19	16	13	11	8	5	3	0					
70	20	17	14	12	9	6	4	1					
71	21	18	15	13	10	8	5	3	0				
72	22	19	16	14	11	9	6	4	1				
73	23	20	17	15	12	10	7	5	3	0			
74	24	21	18	16	13	11	9	6	4	2			
75	25	22	19	17	14	12	10	7	5	3	1		
76	25	23	20	18	15	13	11	8	6	4	2		
77	26	24	21	19	16	14	12	9	7	5	3	1	
78	27	25	22	20	17	15	13	10	8	6	4	2	
79	28	25	23	21	18	16	14	11	9	7	5	3	1
80	29	26	24	21	19	17	15	12	10	8	6	4	2

Air temp., t	Depression of wet-bulb thermometer $(t - t')$															
	1	2	3	4	5	6	7	8	9	10	11	12	12	14	15	16
80	96	92	88	84	80	77	73	70	67	63	60	57	54	51	48	45
82	96	92	88	85	81	77	74	71	67	64	61	58	55	52	49	46
84	96	92	89	85	81	78	74	71	68	65	61	58	55	53	50	47
86	96	92	89	85	81	78	75	71	68	65	62	59	56	53	50	48
88	96	93	89	85	82	79	75	72	69	66	63	60	57	54	51	49
90	96	93	89	86	82	79	76	73	69	66	63	61	58	55	52	50
92	96	93	89	86	83	79	76	73	70	67	64	61	58	56	53	51
94	96	93	89	86	83	80	76	73	70	67	65	62	59	56	54	51
96	96	93	90	86	83	80	77	74	71	68	65	62	60	57	55	52
98	97	93	90	87	83	80	77	74	71	68	66	63	60	58	55	53
100	97	93	90	87	84	80	77	75	72	69	66	64	61	58	56	53
102	97	93	90	87	84	81	78	75	72	69	67	64	61	59	57	54
104	97	93	90	87	84	81	78	75	72	70	67	65	62	59	57	55
106	97	94	90	87	84	81	78	76	73	70	68	65	62	60	58	55
108	97	94	90	87	84	82	79	76	73	71	68	65	63	61	58	56
110	97	94	91	88	85	82	79	76	74	71	68	66	63	61	59	56
112	97	94	91	88	85	82	79	77	74	71	69	66	64	62	59	57
114	97	94	91	88	85	82	80	77	74	72	69	67	64	62	60	58
116	97	94	91	88	85	82	80	77	75	72	70	67	65	62	60	58
118	97	94	91	88	85	83	80	77	75	72	70	67	65	63	61	58
120	97	94	91	88	85	83	80	77	75	73	70	68	65	63	61	59
122	97	94	91	89	86	83	80	78	75	73	71	68	66	64	62	59
124	97	94	91	89	86	83	81	78	76	73	71	68	66	64	62	60
126	97	94	91	89	86	83	81	78	76	74	71	69	67	65	62	60
128	97	94	91	89	86	84	81	79	76	74	72	69	67	65	63	61
130	97	94	92	89	86	84	81	79	76	74	72	70	67	65	63	61
132	97	94	92	89	86	84	81	79	77	74	72	70	68	66	63	61
134	97	95	92	89	87	84	82	79	77	75	72	70	68	66	64	62
136	97	95	92	89	87	84	82	79	77	75	73	70	68	66	64	62
138	97	95	92	89	87	84	82	80	77	75	73	71	69	66	64	62
140	97	95	92	90	87	85	82	80	78	75	73	71	69	67	65	63

Relative Humidity, Per Cent.—Fahrenheit Temperatures. *Continued*

Pressure = 23.0 inches of mercury

t	Depression of wet-bulb thermometer ($t - t'$)															
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
80	42	39	37	34	31	29	26	24	21	19	17	15	12	10	8	6
82	43	40	38	35	33	30	28	25	23	21	19	16	14	12	10	8
84	44	42	39	36	34	31	29	27	24	22	20	18	16	14	12	10
86	45	43	40	38	35	33	30	28	26	24	22	20	17	15	13	12
88	46	44	41	39	36	34	32	29	27	25	23	21	19	17	15	13
90	47	45	42	40	37	35	33	31	28	26	24	22	20	18	17	15
92	48	46	43	41	38	36	34	32	30	28	26	24	22	20	18	16
94	49	46	44	42	39	37	35	33	31	29	27	25	23	21	19	18
96	50	47	45	43	40	38	36	34	32	30	28	26	24	22	21	19
98	50	48	46	43	41	39	37	35	33	31	29	27	25	24	22	20
100	51	49	46	44	42	40	38	36	34	32	30	28	26	25	23	21
102	52	50	47	45	43	41	39	37	35	33	31	29	27	26	24	22
104	52	50	48	46	44	42	40	38	36	34	32	30	28	27	25	23
106	53	51	49	47	44	42	40	38	37	35	33	31	29	28	26	24
108	54	51	49	47	45	43	41	39	37	36	34	32	30	29	27	25
110	54	52	50	48	46	44	42	40	38	36	35	33	31	30	28	26
112	55	53	51	48	46	45	43	41	39	37	35	34	32	30	29	27
114	55	53	51	49	47	45	43	41	40	38	36	34	33	31	30	28
116	56	54	52	50	48	46	44	42	40	39	37	35	34	32	30	29
118	56	54	52	50	48	46	45	43	41	39	38	36	34	33	31	30
120	57	55	53	51	49	47	45	43	42	40	38	37	35	33	32	30
122	57	55	53	51	49	48	46	44	42	41	39	37	36	34	33	31
124	58	56	54	52	50	48	46	45	43	41	39	38	36	35	33	32
126	58	56	54	52	50	49	47	45	43	42	40	39	37	35	34	33
128	59	57	55	53	51	49	47	46	44	42	41	39	38	36	35	33
130	59	57	55	53	51	50	48	46	45	43	41	40	38	37	35	34
132	59	57	56	54	52	50	48	47	45	43	42	40	39	37	36	34
134	60	58	56	54	52	51	49	47	46	44	42	41	39	38	36	35
136	60	58	56	55	53	51	49	48	46	44	43	41	40	38	37	36
138	61	59	57	55	53	51	50	48	46	45	43	42	40	39	37	36
140	61	59	57	55	54	52	50	49	47	45	44	42	41	39	38	37

Relative Humidity, Per Cent.—Fahrenheit Temperatures. *Continued*

Pressure = 23.0 inches of mercury

Air temp., t	Depression of wet-bulb thermometer $(t - t')$															
	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
80	4	2	0													
82	6	4	2	0												
84	8	6	4	2	1											
86	11	8	6	4	2	1										
88	11	10	8	6	4	3	1									
90	13	11	9	8	6	4	3	1								
92	14	13	11	9	8	6	5	3	2	0						
94	16	14	12	11	9	8	6	5	3	2	0					
96	17	15	14	12	11	9	8	6	5	3	2	1	0			
98	18	17	15	14	12	11	9	8	6	5	4	2	1			
100	20	18	16	15	13	12	10	9	8	6	5	4	2	1		
102	21	19	18	16	15	13	12	10	9	8	6	5	4	3	1	0
104	22	20	19	17	16	14	13	12	10	9	8	6	5	4	3	2
106	23	21	20	18	17	16	14	13	11	10	9	8	7	5	4	3
108	24	22	21	19	18	17	15	14	12	11	10	9	8	7	5	4
110	25	23	22	20	19	18	16	15	14	12	11	10	9	8	7	6
112	26	24	23	21	20	19	17	16	15	14	12	11	10	9	8	7
114	27	25	24	22	21	20	18	17	16	15	13	12	11	10	9	8
116	27	26	25	23	22	20	19	18	17	15	14	13	12	11	10	9
118	28	27	25	24	23	21	20	19	18	16	15	14	13	12	11	10
120	29	28	26	25	23	22	21	20	18	17	16	15	14	13	12	11
122	30	28	27	26	24	23	22	21	19	18	17	16	15	14	13	12
124	30	29	28	26	25	24	22	21	20	19	18	17	16	15	14	13
126	31	30	28	27	26	25	23	22	21	20	19	18	16	15	14	13
128	32	30	29	28	26	25	24	23	22	20	19	18	17	16	15	14
130	32	31	30	28	27	26	25	23	22	21	20	19	18	17	16	15
132	33	32	30	29	28	27	25	24	23	22	21	20	19	18	17	16
134	34	32	31	30	28	27	26	25	24	23	21	20	19	18	17	16
136	34	33	32	30	29	28	27	25	24	23	22	21	20	19	18	17
138	35	33	32	31	30	28	27	26	25	24	23	22	21	20	19	18
140	35	34	33	31	30	29	28	27	26	24	23	22	21	20	19	18

TABLE XI.—PRESSURE OF AQUEOUS VAPOR FOR TEMPERATURE FROM 100° TO 445°F., IN INCHES OF MERCURY

Temp., °F.	0	1	2	3	4	5	6	7	8	9
	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches
100	1.916	1.975	2.035	2.097	2.160	2.225	2.292	2.360	2.431	2.503
110	2.576	2.652	2.730	2.810	2.891	2.975	3.061	3.148	3.239	3.331
120	3.425	3.522	3.621	3.723	3.827	3.933	4.042	4.154	4.268	4.385
130	4.504	4.627	4.752	4.880	5.011	5.145	5.282	5.422	5.565	5.712
140	5.862	6.015	6.171	6.331	6.495	6.662	6.832	7.006	7.184	7.366
150	7.552	7.742	7.936	8.133	8.335	8.541	8.752	8.966	9.186	9.409
160	9.637	9.870	10.108	10.350	10.597	10.850	11.107	11.369	11.636	11.909
170	12.187	12.470	12.759	13.054	13.354	13.660	13.972	14.289	14.613	14.943
180	15.279	15.621	15.970	16.325	16.687	17.055	17.430	17.812	18.202	18.598
190	19.001	19.412	19.830	20.255	20.688	21.129	21.578	22.034	22.499	22.972
200	23.45	23.94	24.44	24.95	25.46	25.99	26.52	27.06	27.62	28.18
210	28.75	29.33	29.92	30.52	31.13	31.75	32.38	33.02	33.67	34.33
220	35.01	35.69	36.38	37.08	37.79	38.52	39.26	40.01	40.77	41.55
230	42.34	43.14	43.94	44.76	45.59	46.44	47.31	48.19	49.08	49.98
240	50.89	51.82	52.76	53.72	54.69	55.67	56.67	57.68	58.71	59.76
250	60.82	61.89	62.98	64.08	65.20	66.33	67.48	68.66	69.85	71.04
260	72.26	73.50	74.75	76.02	77.31	78.61	79.93	81.27	82.63	84.01
270	85.41	86.82	88.25	89.70	91.18	92.67	94.18	95.70	97.25	98.82
280	100.41	102.03	103.66	105.32	106.99	108.69	110.41	112.15	113.91	115.69
290	117.50	119.33	121.18	123.05	124.94	126.86	128.81	130.78	132.78	134.80
300	136.8	138.9	141.0	143.1	145.2	147.4	149.6	151.8	154.1	156.4
310	158.7	161.0	162.3	165.7	168.1	170.6	173.0	175.5	178.0	180.5
320	183.1	185.8	188.4	191.1	193.8	196.5	199.3	202.1	204.9	207.7
330	210.6	213.5	216.4	219.4	222.4	225.4	228.5	231.6	234.7	237.9
340	241.1	244.3	247.6	250.9	254.2	257.6	261.1	264.5	268.0	271.5
350	275.1	278.7	282.3	285.9	289.6	293.3	297.1	300.9	304.8	308.7
360	312.6	316.5	320.5	324.6	328.7	332.8	337.0	341.2	345.4	349.7
370	354.1	358.4	362.8	367.3	371.8	376.4	380.9	385.5	390.2	394.9
380	399.7	404.5	409.3	414.1	419.1	424.1	429.1	434.1	439.2	444.4
390	449.7	454.9	460.1	465.5	470.9	476.4	481.9	487.4	493.0	498.7
400	504.4	510.1	515.9	521.7	527.6	533.6	539.5	545.6	551.7	557.9
410	564.1	570.3	576.6	582.9	589.3	595.7	602.3	608.9	615.5	622.1
420	628.8	635.6	642.5	649.4	656.3	663.3	670.4	677.5	684.7	691.9
430	699.2	706.6	714.0	721.4	728.9	736.5	744.2	751.9	759.6	767.4
440	775.3	783.2	791.3	799.3	807.4	815.5				

Weight of a Cubic Foot of Aqueous Vapor at Different Temperatures and Saturations (in Grains)

Temp., °F.	Percentage of saturation									
	10	20	30	40	50	60	70	80	90	100
	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.
—20	0.017	0.033	0.050	0.066	0.083	0.100	0.116	0.133	0.149	0.166
—19	0.017	0.035	0.052	0.070	0.087	0.104	0.122	0.139	0.157	0.174
—18	0.018	0.037	0.055	0.074	0.092	0.100	0.129	0.147	0.166	0.184
—17	0.020	0.039	0.059	0.078	0.098	0.118	0.137	0.157	0.176	0.196
—16	0.021	0.041	0.062	0.083	0.104	0.124	0.145	0.166	0.186	0.207
—15	0.022	0.044	0.065	0.087	0.109	0.131	0.153	0.174	0.196	0.218
—14	0.023	0.046	0.069	0.092	0.116	0.139	0.162	0.185	0.208	0.231
—13	0.024	0.049	0.073	0.097	0.122	0.146	0.170	0.194	0.219	0.243
—12	0.026	0.051	0.077	0.103	0.128	0.154	0.180	0.206	0.231	0.257
—11	0.027	0.054	0.081	0.108	0.135	0.162	0.189	0.216	0.243	0.270
—10	0.028	0.057	0.086	0.114	0.142	0.171	0.200	0.228	0.256	0.285
— 9	0.030	0.060	0.090	0.120	0.150	0.180	0.210	0.240	0.270	0.300
— 8	0.032	0.063	0.095	0.126	0.158	0.190	0.221	0.253	0.284	0.316
— 7	0.033	0.066	0.100	0.133	0.166	0.199	0.232	0.266	0.299	0.332
— 6	0.035	0.070	0.105	0.140	0.175	0.210	0.245	0.280	0.315	0.350
— 5	0.037	0.074	0.111	0.148	0.185	0.222	0.259	0.296	0.333	0.370
— 4	0.039	0.078	0.117	0.156	0.194	0.233	0.272	0.311	0.350	0.389
— 3	0.041	0.082	0.123	0.164	0.206	0.247	0.288	0.329	0.370	0.411
2	0.043	0.087	0.130	0.174	0.217	0.260	0.304	0.347	0.391	0.434
1	0.046	0.091	0.137	0.183	0.228	0.274	0.320	0.366	0.411	0.457
0	0.048	0.096	0.144	0.192	0.240	0.289	0.337	0.385	0.433	0.481
1	0.050	0.101	0.152	0.202	0.252	0.303	0.354	0.404	0.454	0.505
2	0.053	0.106	0.159	0.212	0.264	0.317	0.370	0.423	0.476	0.529
3	0.055	0.111	0.166	0.222	0.277	0.332	0.388	0.443	0.499	0.554
4	0.058	0.116	0.175	0.233	0.291	0.349	0.407	0.466	0.524	0.582
5	0.061	0.122	0.183	0.244	0.305	0.366	0.427	0.488	0.549	0.610
6	0.064	0.128	0.192	0.256	0.320	0.383	0.447	0.511	0.575	0.639
7	0.067	0.134	0.201	0.268	0.336	0.403	0.470	0.537	0.604	0.671
8	0.070	0.141	0.211	0.282	0.352	0.422	0.493	0.563	0.634	0.704
9	0.074	0.148	0.222	0.296	0.370	0.443	0.517	0.591	0.665	0.739
10	0.078	0.155	0.233	0.310	0.388	0.466	0.543	0.621	0.698	0.776
11	0.082	0.163	0.245	0.326	0.408	0.490	0.571	0.653	0.734	0.816
12	0.086	0.171	0.257	0.342	0.428	0.514	0.599	0.685	0.770	0.856
13	0.090	0.180	0.269	0.359	0.449	0.539	0.629	0.718	0.808	0.898
14	0.094	0.188	0.282	0.376	0.470	0.565	0.659	0.753	0.847	0.941
15	0.099	0.197	0.296	0.394	0.493	0.592	0.690	0.789	0.887	0.986
16	0.103	0.206	0.310	0.413	0.516	0.619	0.722	0.826	0.929	1.032
17	0.108	0.216	0.324	0.432	0.540	0.648	0.756	0.864	0.972	1.080
18	0.113	0.226	0.338	0.451	0.564	0.677	0.790	0.902	1.015	1.128
19	0.118	0.236	0.354	0.472	0.590	0.709	0.827	0.845	1.063	1.181
20	0.124	0.247	0.370	0.494	0.618	0.741	0.864	0.988	1.112	1.235
21	0.129	0.259	0.388	0.518	0.647	0.776	0.906	1.035	1.165	1.294
22	0.136	0.271	0.406	0.542	0.678	0.813	0.948	1.084	1.220	1.355
23	0.142	0.284	0.425	0.567	0.709	0.851	0.993	1.134	1.276	1.418
24	0.148	0.297	0.445	0.593	0.742	0.890	1.038	1.186	1.335	1.483
25	0.155	0.310	0.465	0.620	0.776	0.931	1.086	1.241	1.396	1.551
26	0.162	0.325	0.487	0.649	0.812	0.974	1.136	1.298	1.461	1.623
27	0.170	0.339	0.509	0.679	0.848	1.018	1.188	1.358	1.527	1.697

Weight of a Cubic Foot of Aqueous Vapor at Different Temperatures and Saturations (in Grains). *Continued*

Temp., °F.	Percentage of saturation									
	10	20	30	40	50	60	70	80	90	100
	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.
28	0.177	0.355	0.532	0.709	0.886	1.064	1.241	1.418	1.596	1.773
29	0.185	0.371	0.556	0.741	0.926	1.112	1.297	1.482	1.668	1.853
30	0.194	0.387	0.580	0.774	0.968	1.161	1.354	1.548	1.742	1.935
31	0.202	0.404	0.607	0.809	1.011	1.213	1.415	1.618	1.820	2.022
32	0.211	0.422	0.634	0.845	1.056	1.268	1.479	1.690	1.902	2.113
33	0.219	0.439	0.658	0.878	1.097	1.316	1.536	1.755	1.975	2.194
34	0.228	0.456	0.684	0.912	1.140	1.367	1.595	1.823	2.051	2.279
35	0.237	0.473	0.710	0.946	1.183	1.420	1.656	1.893	2.129	2.366
36	0.246	0.491	0.737	0.983	1.228	1.474	1.720	1.966	2.211	2.457
37	0.255	0.510	0.765	1.020	1.275	1.530	1.785	2.040	2.295	2.550
38	0.265	0.529	0.794	1.058	1.323	1.588	1.852	2.117	2.381	2.646
39	0.275	0.549	0.824	1.098	1.373	1.648	1.922	2.197	2.471	2.746
40	0.285	0.570	0.855	1.140	1.424	1.709	1.994	2.279	2.564	2.849
41	0.296	0.591	0.886	1.182	1.478	1.773	2.068	2.364	2.660	2.955
42	0.306	0.613	0.919	1.226	1.532	1.838	2.145	2.451	2.758	3.064
43	0.318	0.635	0.953	1.271	1.588	1.906	2.224	2.542	2.859	3.177
44	0.329	0.659	0.988	1.318	1.647	1.976	2.306	2.635	2.965	3.294
45	0.341	0.683	1.024	1.366	1.707	2.048	2.390	2.731	3.073	3.414
46	0.354	0.708	1.062	1.416	1.770	2.123	2.477	2.831	3.185	3.539
47	0.367	0.733	1.100	1.467	1.834	2.200	2.567	2.934	3.300	3.667
48	0.380	0.760	1.140	1.520	1.900	2.280	2.660	3.040	3.420	3.800
49	0.394	0.787	1.181	1.574	1.968	2.362	2.755	3.149	3.542	3.936
50	0.408	0.815	1.223	1.630	2.038	2.446	2.853	3.261	3.668	4.076
51	0.422	0.844	1.267	1.689	2.111	2.533	2.955	3.378	3.800	4.222
52	0.437	0.874	1.312	1.749	2.186	2.623	3.060	3.498	3.935	4.372
53	0.453	0.907	1.358	1.810	2.263	2.716	3.168	3.621	4.073	4.526
54	0.468	0.937	1.406	1.874	2.342	2.811	3.280	3.748	4.216	4.685
55	0.485	0.970	1.455	1.940	2.424	2.909	3.394	3.879	4.364	4.849
56	0.502	1.003	1.505	2.006	2.508	3.010	3.511	4.013	3.514	5.016
57	0.519	1.038	1.557	2.076	2.596	3.115	3.634	4.153	4.672	5.191
58	0.537	1.074	1.611	2.148	2.685	3.222	3.759	4.296	4.833	5.370
59	0.556	1.111	1.666	2.222	2.778	3.333	3.888	4.444	5.000	5.555
60	0.574	1.149	1.724	2.298	2.872	3.447	4.022	4.596	5.170	5.745
61	0.594	1.188	1.782	2.376	2.970	3.565	4.159	4.753	5.347	5.941
62	0.614	1.228	1.843	2.457	3.071	3.685	4.299	4.914	5.528	6.142
63	0.635	1.270	1.905	2.540	3.174	3.809	4.444	5.079	5.714	6.349
64	0.656	1.313	1.969	2.625	3.282	3.938	4.594	5.250	5.907	6.563
65	0.678	1.356	2.035	2.713	3.391	4.069	4.747	5.426	6.104	6.782
66	0.701	1.402	2.103	2.804	3.504	4.205	4.906	5.607	6.308	7.009
67	0.724	1.448	2.172	2.896	3.620	4.345	5.069	5.793	6.517	7.241
68	0.748	1.496	2.244	2.992	3.740	4.488	5.236	5.984	6.732	7.480
69	0.773	1.545	2.318	3.090	3.863	4.636	5.408	6.181	6.953	7.726
70	0.798	1.596	2.394	3.192	3.990	4.788	5.586	6.384	7.182	7.980
71	0.824	1.648	2.472	3.296	4.120	4.944	5.768	6.592	7.416	8.240
72	0.851	1.702	2.552	3.403	4.254	5.105	5.956	6.806	7.657	8.508
73	0.878	1.756	2.635	3.513	4.391	5.269	6.147	7.026	7.904	8.782
74	0.907	1.813	2.720	3.626	4.533	5.440	6.346	7.253	8.159	9.066

Weight of a Cubic Foot of Aqueous Vapor at Different Temperatures and Saturations (in Grains). *Continued*

Temp., °F.	Percentage of saturation									
	10	20	30	40	50	60	70	80	90	100
	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.
75	0.936	1.871	2.807	3.742	4.678	5.614	6.549	7.485	8.420	9.356
76	0.966	1.931	2.896	3.862	4.828	5.793	6.758	7.724	8.690	9.655
77	0.996	1.992	2.989	3.985	4.981	5.977	6.973	7.970	8.966	9.962
78	1.028	2.055	3.083	4.111	5.138	6.166	7.194	8.222	9.249	10.277
79	1.060	2.120	3.180	4.240	5.300	6.361	7.421	8.481	9.541	10.601
80	1.093	2.187	3.280	4.374	5.467	6.560	7.654	8.747	9.841	10.934
81	1.128	2.255	3.382	4.510	5.638	6.765	7.892	9.020	10.148	11.275
82	1.163	2.325	3.488	4.650	5.813	6.976	8.138	9.301	10.463	11.626
83	1.199	2.397	3.596	4.795	5.994	7.192	8.391	9.590	10.788	11.987
84	1.236	2.471	3.707	4.942	6.178	7.414	8.649	9.885	11.120	12.356
85	1.274	2.547	3.821	5.094	6.368	7.642	8.915	10.189	11.462	12.736
86	1.313	2.625	3.938	5.251	6.564	7.877	9.189	10.502	11.814	13.127
87	1.353	2.705	4.058	5.410	6.763	8.116	9.468	10.821	12.173	13.526
88	1.394	2.787	4.181	5.575	6.968	8.362	9.756	11.150	12.543	13.937
89	1.436	2.872	4.308	5.744	7.180	8.615	10.051	11.487	12.923	14.359
90	1.479	2.958	4.437	5.916	7.395	8.874	10.353	11.832	13.311	14.790
91	1.523	3.047	4.570	6.094	7.617	9.140	10.664	12.187	13.711	15.234
92	1.569	3.138	4.707	6.276	7.844	9.413	10.982	12.551	14.120	15.689
93	1.616	3.231	4.846	6.462	8.078	9.693	11.308	12.924	14.540	16.155
94	1.663	3.327	4.990	6.654	8.317	9.980	11.644	13.307	14.971	16.634
95	1.712	3.425	5.137	6.850	8.562	10.274	11.987	13.699	15.412	17.124
96	1.763	3.525	5.288	7.050	8.813	10.576	12.338	14.101	15.863	17.626
97	1.814	3.628	5.443	7.257	9.071	10.885	12.699	14.514	16.328	18.142
98	1.867	3.734	5.601	7.468	9.336	11.203	13.070	14.937	16.804	18.671
99	1.921	3.842	5.764	7.685	9.606	11.527	13.448	15.370	17.291	19.212
100	1.977	3.953	5.930	7.906	9.883	11.860	13.836	15.813	17.789	19.766
101	2.034	4.067	6.100	8.134	10.168	12.201	14.234	16.268	18.302	20.335
102	2.092	4.183	6.275	8.367	10.458	12.550	14.642	16.734	18.825	20.917
103	2.151	4.303	6.454	8.606	10.757	12.908	15.060	17.211	19.363	21.514
104	2.212	4.425	6.638	8.850	11.062	13.275	15.488	17.700	19.912	22.125
105	2.275	4.550	6.825	9.100	11.375	13.650	15.925	18.200	20.475	22.750
106	2.339	4.678	7.018	9.357	11.696	14.035	16.374	18.714	21.053	23.392
107	2.405	4.809	7.214	9.619	12.024	14.429	16.834	19.238	21.643	24.048
108	2.472	4.944	7.416	9.888	12.360	14.832	17.304	19.776	22.248	24.720
109	2.541	5.082	7.622	10.163	12.704	15.245	17.786	20.326	22.867	25.408
110	2.611	5.222	7.834	10.445	13.056	15.667	18.278	20.890	23.501	26.112

Tension of Aqueous Vapor at Various Temperatures[1]

Temperature, degrees C.	Tension of aqueous vapor in mm.	Temperature, degrees C.	Tension of aqueous vapor in mm.
0	4.525	21	18.505
1	4.867	22	19.675
2	5.231	23	20.909
3	5.619	24	22.211
4	6.032	25	23.582
5	6.471	26	25.026
6	6.939	27	26.547
7	7.436	28	28.148
8	7.964	29	29.832
9	8.525	30	31.602
10	9.126	31	33.464
11	9.751	32	35.419
12	10.421	33	37.473
13	11.130	34	39.630
14	11.882	35	41.893
15	12.677	36	44.268
16	13.519	37	46.758
17	14.409	38	49.368
18	15.351	39	52.103
19	16.345	40	54.969
20	17.396	....	....

[1] Winkler, "Technical Gas Analysis."

BAROMETRIC CORRECTIONS

Corrections for Temperature
(Mercury, brass scale correct at 0°C.)

Temperature	Millimeters						
	73	74	75	76	77	78	79
15°	0.178	0.181	0.183	0.186	0.188	0.191	0.193
16	0.190	0.193	0.196	0.198	0.201	0.203	0.206
17	0.202	0.205	0.208	0.210	0.213	0.216	0.218
18	0.214	0.217	0.220	0.223	0.226	0.229	0.231
19	0.226	0.229	0.232	0.235	0.238	0.241	0.244
20	0.238	0.241	0.244	0.247	0.251	0.254	0.257
21	0.250	0.253	0.256	0.260	0.263	0.267	0.270
22	0.261	0.265	0.269	0.272	0.276	0.279	0.283
23	0.273	0.277	0.281	0.284	0.288	0.292	0.296
24	0.289	0.289	0.293	0.297	0.301	0.305	0.309

Corrections must be subtracted from observed readings, if reading at 19°C. is 76 cm., the corrected reading is 76 − 0.235.

Effect of Altitude[1]

Table of altitudes in feet above sea-level; with corresponding approximate barometric readings, atmospheric pressures and proportionate densities. (The capacity of an internal combustion engine at higher altitudes, as compared with its capacity at sea-level, is practically proportional to the atmospheric densities.)

Altitude in feet	Barometer in inches	Atmospheric pressure in pounds per square inch	Proportionate atmospheric density
0.00	30.0	14.72	1.00
500.0	29.5	14.45	0.98
1,000.0	28.9	14.18	0.96
1,500.0	28.4	13.94	0.94
2,000.0	27.9	13.69	0.93
2,500.0	27.4	13.45	0.91
3,000.0	26.9	13.20	0.89
4,000.0	26.0	12.75	0.86
5,000.0	25.1	12.30	0.83
6,000.0	24.2	11.85	0.80
7,000.0	23.3	11.44	0.77
8,000.0	22.5	11.04	0.75
9,000.0	21.7	10.65	0.73
10,000.0	20.9	10.26	0.70

[1] From the "Diesel Engine," Busch-Sulzer Bros. Diesel Engine Co.

Correction to be Added for Capillarity

Diameter tube in inches	Height of meniscus in inches							
	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08
0.15	0.024	0.047	0.069	0.092	0.116	......	......	......
0.20	0.011	0.022	0.033	0.045	0.059	0.079	......	......
0.25	0.006	0.012	0.019	0.028	0.037	0.047	0.059	......
0.30	0.004	0.008	0.013	0.018	0.023	0.029	0.035	0.042
0.35	......	0.005	0.008	0.012	0.015	0.019	0.022	0.027
0.40	......	0.004	0.006	0.008	0.010	0.012	0.014	0.016
0.45	......	......	0.003	0.005	0.007	0.008	0.010	0.012
0.50	......	......	0.002	0.004	0.005	0.006	0.006	0.007
0.55	......	......	0.001	0.002	0.003	0.004	0.005	0.005

From Ellenwood's "Steam Charts," abbr. from Smithsonian table No. 103.

Barometer Correction for Variation in g—Correct at 45° N. or S. Latitude

	73	74	75	76	77	78	79
35° or 55°	0.065	0.066	0.066	0.067	0.068	0.069	0.070
40° or 50°	0.032	0.033	0.033	0.034	0.035	0.035	0.035

Subtract the correction for 35° and 40°.
Add the correction for 50° and 55°.

Batteries, E.m.f. of Standard Cells

Cell	Description	E.m.f.	Resistance
Bichromate	Zn and C in 1 vol. strong H_2SO_4 and 20 vol. sat. $K_2Cr_2O_7$ sol.	2.0	Very low
Bunsen	Zn in 1 vol. strong H_2SO_4 : 12 vol. H_2O C in strong HNO_3.	1.8–1.9	....
Clark	Zn amalgam and Hg in sat. $ZnSO_4$ sol.	1.433	About 500
Daniell	Zn in $ZnSO_4$ sol. or H_2SO_4 (1:12) Cu in sat. $CuSO_4$ sol.	1.07–1.08	About 4
Grove	Like Bunsen, C replaced by Pt.	1.8–1.9	....
Leclanché	Zn and C in NH_4Cl, C and MnO_2.	1.5	0.25–0.4
Secondary	Pb and PbO_2 in H_2SO_4 of density 1.2	2.2–1.9	....
Tucker	Zn and C with sat. $CaCl_2$ sol.	1.4	....
Weston	Cd amalgam. and Hg in sat. $CdSO_4$ sol.	1.018	About 500

Hydrometer Conversion Factors

Liquids lighter than water
$$\frac{140}{\text{Bé.}^\circ + 130} = \text{sp. gr.}$$
$$\frac{140}{\text{sp. gr.}} - 130 = \text{Bé.}^\circ$$

Liquids heavier than water
$$\text{Sp. gr.} = \frac{145}{145 - \text{Bé.}^\circ}$$
$$\text{Bé.}^\circ = 145 - \frac{145}{\text{sp. gr.}}$$

To correct Bé. readings to 60°: Correct reading = observed reading + $\frac{60 - t}{10}$

For the Twaddell hydrometer:

$$\frac{\text{Tw.}^\circ}{200} + 1 = \text{sp. gr.}$$
$$200(\text{sp. gr.} - 1) = \text{Tw.}^\circ$$

For the Gay-Lussac (standardized at 4°C.):

$$\frac{100}{\text{G.-L.}^\circ + 100} = \text{sp. gr.}$$
$$\frac{100}{\text{sp. gr.}} - 100 = \text{G.-L.}^\circ$$

For the Sikes hydrometer: 1° = 0.002 of sp. gr.

For the Beck (12.5°C.): sp. gr. $= \frac{170}{170 + \text{Beck}^\circ}$

For the Cartier (12.5°): sp. gr. $= \frac{136}{126.1 + \text{Cart.}^\circ}$

For the Brix and the Fisher (15.6°C.): sp. gr. $= \frac{400}{400 + n^\circ}$

Conversion Table for Degrees Baumé[1]

(Liquids lighter than water[2])

Degrees Baumé	Sp. gr.	Pounds in 1 gal. American[3]	Degrees Baumé	Sp. gr.	Pounds in 1 gal. American[3]
10	1.0000	8.33	43	0.8092	6.74
11	0.9929	8.27	44	0.8045	6.70
12	0.9859	8.21	45	0.8000	6.66
13	0.9790	8.16	46	0.7954	6.63
14	0.9722	8.10	47	0.7909	6.59
15	0.9655	8.04	48	0.7865	6.55
16	0.9589	7.99	49	0.7821	6.52
17	0.9523	7.93	50	0.7777	6.48
18	0.9459	7.88	51	0.7734	6.44
19	0.9395	7.83	52	0.7692	6.41
20	0.9333	7.78	53	0.7650	6.37
21	0.9271	7.72	54	0.7608	6.34
22	0.9210	7.67	55	0.7567	6.30
23	0.9150	7.62	56	0.7526	6.27
24	0.9090	7.57	57	0.7486	6.24
25	0.9032	7.53	58	0.7446	6.20
26	0.8974	7.48	59	0.7407	6.17
27	0.8917	7.43	60	0.7368	6.14
28	0.8860	7.38	61	0.7329	6.11
29	0.8805	7.34	62	0.7290	6.07
30	0.8750	7.29	63	0.7253	6.04
31	0.8695	7.24	64	0.7216	6.01
32	0.8641	7.20	65	0.7179	5.98
33	0.8588	7.15	66	0.7142	5.95
34	0.8536	7.11	67	0.7106	5.92
35	0.8484	7.07	68	0.7070	5.89
36	0.8433	7.03	69	0.7035	5.86
37	0.8383	6.98	70	0.7000	5.83
38	0.8333	6.94	71	0.6829	5.69
39	0.8284	6.90	72	0.6666	5.55
40	0.8235	6.86	73	0.6511	5.42
41	0.8187	6.82	74	0.6363	5.30
42	0.8139	6.78	75	0.6222	5.18

[1] The Baumé scale is entirely arbitrary, so various authorities give various values for the above table. These given above are from a table specially calculated for the "Petroleum Year Book, 1914" by Tagliabue of New York. The formulas on p. 112 were also furnished by him for the same work.

[2] For liquids heavier than water, see the sulphuric acid table on page 115.

[3] Sp. gr. × 10 = pounds per imperial gallon.

Specific Gravity of Sulphuric Acid[1] at 15°C., Compared to Water at 4°C.

Sp. gr. at $\frac{15°}{4°}$	Degrees Baumé	Degrees Twaddell	100 parts of c.p. acid contain, per cent.			
			SO_3	H_2SO_4	60°Bé. acid	50°Bé. acid
1.000	0.0	0	0.07	0.09	0.12	0.14
1.005	0.7	1	0.68	0.83	1.06	1.33
1.010	1.4	2	1.28	1.57	2.01	2.51
1.015	2.1	3	1.88	2.30	2.95	3.68
1.020	2.7	4	2.47	3.03	3.88	4.85
1.025	3.4	5	3.07	3.76	4.82	6.02
1.030	4.1	6	3.67	4.49	5.78	7.18
1.035	4.7	7	4.27	5.23	6.73	8.37
1.040	5.4	8	4.87	5.96	7.64	9.54
1.045	6.0	9	5.45	6.67	8.55	10.67
1.050	6.7	10	6.02	7.37	9.44	11.79
1.055	7.4	11	6.59	8.07	10.34	12.91
1.060	8.0	12	7.16	8.77	11.24	14.03
1.065	8.7	13	7.73	9.47	12.14	15.15
1.070	9.4	14	8.32	10.19	13.05	16.30
1.075	10.0	15	8.90	10.90	13.96	17.44
1.080	10.6	16	9.47	11.60	14.87	18.56
1.085	11.2	17	10.04	12.30	15.76	19.68
1.090	11.9	18	10.60	12.99	16.65	20.78
1.095	12.4	19	11.16	13.67	17.52	21.87
1.100	13.0	20	11.71	14.35	18.39	22.96
1.105	13.6	21	12.27	15.03	19.26	24.05
1.110	14.2	22	12.82	15.71	20.13	25.14
1.115	14.9	23	13.36	16.36	20.96	26.18
1.120	15.4	24	13.89	17.01	21.80	27.22
1.125	16.0	25	14.42	17.66	22.63	28.26
1.130	16.5	26	14.95	18.31	23.47	29.30
1.135	17.1	27	15.48	18.96	24.29	30.34
1.140	17.7	28	16.01	19.61	25.13	31.38
1.145	18.3	29	16.54	20.26	25.96	32.42
1.150	18.8	30	17.07	20.91	26.79	33.46
1.155	19.3	31	17.59	21.55	27.61	34.48
1.160	19.8	32	18.11	22.19	28.43	35.50
1.165	20.3	33	18.64	22.83	29.35	36.53
1.170	20.9	34	19.16	23.47	30.07	37.55
1.175	21.4	35	19.69	24.12	30.90	38.59

SPECIFIC GRAVITY OF SULPHURIC ACID[1] AT 15°C., COMPARED TO WATER AT 4°C. *Continued*

Sp. gr. at $\frac{15°}{4°}$	Degrees Baumé	Degrees Twaddell	100 parts of c.p. acid contain, per cent.			
			SO_3	H_2SO_4	60°Bé. acid	50°Bé. acid
1.180	22.0	36	20.21	24.76	31.73	39.62
1.185	22.5	37	20.73	25.40	32.55	40.64
1.190	23.0	38	21.26	26.04	33.37	41.66
1.195	23.5	39	21.78	26.68	34.19	42.69
1.200	24.0	40	22.30	27.32	35.01	43.71
1.205	24.5	41	22.82	27.95	35.83	44.72
1.210	25.0	42	23.33	28.58	36.66	45.73
1.215	25.5	43	23.84	29.21	37.45	46.74
1.220	26.0	44	24.36	29.84	38.23	47.74
1.225	26.4	45	24.88	30.48	39.05	48.77
1.230	26.9	46	25.39	31.11	39.86	49.78
1.235	27.4	47	25.88	31.70	40.61	50.72
1.240	27.9	48	26.35	32.28	41.37	51.65
1.245	28.4	49	26.83	32.86	42.11	52.58
1.250	28.8	50	27.29	33.43	42.84	53.49
1.255	29.3	51	27.76	34.00	43.57	54.40
1.260	29.7	52	28.22	34.57	44.30	55.31
1.265	30.2	53	28.69	35.14	45.03	56.22
1.270	30.6	54	29.15	35.71	45.76	57.14
1.275	31.1	55	29.62	36.29	46.50	58.06
1.280	31.5	56	30.10	36.87	47.24	58.99
1.285	32.0	57	30.57	37.45	47.99	59.92
1.290	32.4	58	31.04	38.03	48.73	60.85
1.295	32.8	59	31.52	38.61	49.47	61.78
1.300	33.3	60	31.99	39.19	50.21	62.70
1.305	33.7	61	32.46	39.77	50.96	63.63
1.310	34.2	62	32.94	40.35	51.71	64.56
1.315	34.6	63	33.41	40.93	52.45	65.45
1.320	35.0	64	33.88	41.50	53.18	66.40
1.325	35.4	65	34.35	42.08	53.92	67.33
1.330	35.8	66	34.80	42.66	54.67	68.26
1.335	36.2	67	35.27	43.20	55.36	69.12
1.340	36.6	68	35.71	43.74	56.05	69.98
1.345	37.0	69	36.14	44.28	56.74	70.85
1.350	37.4	70	36.58	44.82	57.43	71.71
1.355	37.8	71	37.02	45.35	58.11	72.56

Specific Gravity of Sulphuric Acid[1] at 15°C., Compared to Water at 4°C *Continued*

Sp. gr. at $\frac{15°}{4°}$	Degrees Baumé	Degrees Twaddell	100 parts of c.p. acid contain, per cent.			
			SO_3	H_2SO_4	60°Bé. acid	50°Bé. acid
1.360	38.2	72	37.45	45.88	58.79	73.41
1.365	38.6	73	37.89	46.41	59.48	74.26
1.370	39.0	74	38.32	46.94	60.15	75.10
1.375	39.4	75	38.75	47.47	60.83	75.95
1.380	39.8	76	39.18	48.00	61.51	76.80
1.385	40.1	77	39.62	48.53	62.19	77.65
1.390	40.5	78	40.05	49.06	62.87	78.50
1.395	40.8	79	40.48	49.59	63.55	79.34
1.400	41.2	80	40.91	50.11	64.21	80.18
1.405	41.6	81	41.33	50.63	64.88	81.01
1.410	42.0	82	41.76	51.15	65.55	81.86
1.415	42.3	83	42.17	51.66	66.21	82.66
1.420	42.7	84	42.57	52.15	66.82	83.44
1.425	43.1	85	42.96	52.63	67.44	84.21
1.430	43.4	86	43.36	53.11	68.06	84.98
1.435	43.8	87	43.75	53.59	68.68	85.74
1.440	44.1	88	44.14	54.07	69.29	86.51
1.445	44.4	89	44.53	54.55	69.90	87.28
1.450	44.8	90	44.92	55.03	70.52	88.05
1.455	45.1	91	45.31	55.50	71.12	88.80
1.460	45.4	92	45.69	55.97	71.72	89.55
1.465	45.8	93	46.07	56.43	72.31	90.29
1.470	46.1	94	46.45	56.90	72.91	91.04
1.475	46.4	95	46.83	57.37	73.51	91.79
1.480	46.8	96	47.21	57.83	74.10	92.53
1.485	47.1	97	47.57	58.28	74.68	93.25
1.490	47.4	98	47.95	58.74	75.27	93.98
1.495	47.8	99	48.34	59.22	75.88	94.75
1.500	48.1	100	48.73	59.70	76.50	95.52
1.505	48.4	101	49.12	60.18	77.12	96.29
1.510	48.7	102	49.51	60.65	77.72	97.04
1.515	49.0	103	49.89	61.12	78.32	97.79
1.520	49.4	104	50.28	61.59	78.93	98.54
1.525	49.7	105	50.66	62.06	79.52	99.30
1.530	50.0	106	51.04	62.53	80.13	100.05

ific Gravity of Sulphuric Acid[1] at 15°C., Compared to Water at 4°C. *Continued*

r. at	Degrees Baumé	Degrees Twaddell	100 parts of c.p. acid contain, per cent.			
			SO_3	H_2SO_4	60°Bé. acid	50°Bé. acid
35	50.3	107	51.43	63.00	80.73	100.80
40	50.6	108	51.78	63.43	81.28	101.49
45	50.9	109	52.12	63.85	81.81	102.16
50	51.2	110	52.46	64.26	82.34	102.82
55	51.5	111	52.79	64.67	82.87	103.47
60	51.8	112	53.12	65.08	83.39	104.13
65	52.1	113	53.46	65.49	83.92	104.78
70	52.4	114	53.80	65.90	84.44	105.44
75	52.7	115	54.13	66.30	84.95	106.08
80	53.0	116	54.46	66.71	85.48	106.73
85	53.3	117	54.80	67.13	86.03	107.41
90	53.6	118	55.18	67.59	86.62	108.14
95	53.9	119	55.55	68.05	87.20	108.88
00	54.1	120	55.93	68.51	87.79	109.62
05	54.4	121	56.30	68.97	88.38	110.35
10	54.7	122	56.68	69.43	88.97	111.09
15	55.0	123	57.05	69.89	89.56	111.82
20	55.2	124	57.40	70.32	90.11	112.51
25	55.5	125	57.75	70.74	90.65	113.18
30	55.8	126	58.09	71.16	91.19	113.86
35	56.0	127	58.43	71.57	91.71	114.51
40	56.3	128	58.77	71.99	92.25	115.18
45	56.6	129	59.10	72.40	92.77	115.84
50	56.9	130	59.45	72.82	93.29	116.51
55	57.1	131	59.78	73.23	93.81	117.17
60	57.4	132	60.11	73.64	94.36	117.82
65	57.7	133	60.46	74.07	94.92	118.51
70	57.9	134	60.82	74.51	95.48	119.22
75	58.2	135	61.20	74.97	96.07	119.95
80	58.4	136	61.57	75.42	96.65	120.67
85	58.7	137	61.93	75.86	97.21	121.38
90	58.9	138	62.29	76.30	97.77	122.08
95	59.2	139	62.64	76.73	98.32	122.77
00	59.5	140	63.00	77.17	98.89	123.47
05	59.7	141	63.35	77.60	99.44	124.16
10	60.0	142	63.70	78.04	100.00	124.86

Specific Gravity of Sulphuric Acid[1] at 15°C., Compa Water at 4°C. *Continued*

Sp. gr. at $\frac{15°}{4°}$	Degrees Baumé	Degrees Twaddell	100 parts of c.p. acid contain, p			
			SO_3	H_2SO_4	60°Bé. acid	
1.715	60.2	143	64.07	78.48	100.56	1
1.720	60.4	144	64.43	78.92	101.13	1
1.725	60.6	145	64.78	79.36	101.69	1
1.730	60.9	146	65.14	79.80	102.25	1
1.735	61.1	147	65.50	80.24	102.82	1
1.740	61.4	148	65.86	80.68	103.38	1
1.745	61.6	149	66.22	81.12	103.95	1
1.750	61.8	150	66.58	81.56	104.52	1
1.755	62.1	151	66.94	82.00	105.08	1
1.760	62.3	152	67.30	82.44	105.64	1
1.765	62.5	153	67.65	82.88	106.21	1
1.770	62.8	154	68.02	83.32	106.77	1
1.775	63.0	155	68.49	83.90	107.51	1
1.780	63.2	156	68.98	84.50	108.27	1
1.785	63.5	157	69.47	85.10	109.05	1
1.790	63.7	158	69.96	85.70	109.82	1
1.795	64.0	159	70.45	86.30	110.58	1
1.800	64.2	160	70.94	86.90	111.35	1
1.805	64.4	161	71.50	87.60	112.25	1
1.810	64.6	162	72.08	88.30	113.15	1
1.815	64.8	163	72.69	89.05	114.11	1
1.820	65.0	164	73.51	90.05	115.33	1
1.821	....	....	73.63	90.20	115.59	1
1.822	65.1	....	73.80	90.40	115.84	1
1.823	....	....	73.96	90.60	116.10	1
1.824	65.2	....	74.12	90.80	116.35	1
1.825	....	165	74.29	91.00	116.61	1
1.826	65.3	....	74.49	91.25	116.93	1
1.827	....	....	74.69	91.50	117.25	1
1.828	65.4	....	74.86	91.70	117.51	1
1.829	....	....	75.03	91.90	117.76	1
1.830	....	166	75.19	92.10	118.02	1
1.831	65.5	....	75.35	92.30	118.27	1
1.832	....	....	75.53	92.52	118.56	1
1.833	65.6	....	75.72	92.75	118.85	1

SPECIFIC GRAVITY OF SULPHURIC ACID[1] AT 15°C., COMPARED TO WATER AT 4°C. *Continued*

Sp. gr. at $\frac{15^\circ}{4^\circ}$	Degrees Baumé	Degrees Twaddell	100 parts of c.p. acid contain, per cent.			
			SO_3	H_2SO_4	60°Bé. acid	50°Bé. acid
1.834	....	....	75.96	93.05	119.23	148.88
1.835	65.7	167	76.27	93.43	119.72	149.49
1.836	....	....	76.57	93.80	120.19	150.08
1.837	....	....	76.90	94.20	120.71	150.72
1.838	65.8	....	77.23	94.60	121.22	151.36
1.839	....	....	77.55	95.00	121.74	152.00
1.840	65.9	168	78.04	95.60	122.51	152.96
1.8405	....	....	78.33	95.95	122.96	153.52
1.8410	....	....	79.19	97.00	124.30	155.20
1.8415	....	....	79.76	97.70	125.20	156.32
1.8410	....	....	80.16	98.20	125.84	157.12
1.8405	....	....	80.57	98.70	126.48	157.92
1.8400	....	....	80.98	99.20	127.12	158.72
1.8395	....	....	81.18	99.45	127.44	159.12
1.8390	....	....	81.39	99.70	127.76	159.52
1.8385	....	....	81.59	99.95	128.08	159.92

[1] According to LUNGE and ISLER; and LUNGE and NAEF. LUNGE, "The Manufacture of Sulphuric Acid and Alkali," D. VAN NOSTRAND & Co., New York.

To reduce specific gravities observed at other temperatures than 15°C. to 15°C., roughly: For each degree above or below 15°, add to or subtract from the specific gravity observed:

0.0006 with acids to 1.170
0.0007 with acids from 1.170 to 1.450
0.0008 with acids from 1.450 to 1.580
0.0009 with acids from 1.580 to 1.750
0.0010 with acids from 1.750 to 1.840

Specific Gravity of Hydrochloric Acid

Sp. gr. $\frac{15°}{4°}$	Degrees Baumé	Degrees Twaddell	100 parts acid contain by w		
			Per cent., HCl	Per cent., 18° a id	Per cent., 20° acid
1.000	0.0	0.0	0.16	0.57	0.49
1.005	0.7	1	1.15	4.08	3.58
1.010	1.4	2	2.14	7.60	6.66
1.015	2.1	3	3.12	11.08	9.71
1.020	2.7	4	4.13	14.67	12.86
1.025	3.4	5	5.15	18.30	16.04
1.030	4.1	6	6.15	21.85	19.16
1.035	4.7	7	7.15	25.40	22.27
1.040	5.4	8	8.16	28.99	25.42
1.045	6.0	9	9.16	32.55	28.53
1.050	6.7	10	10.17	36.14	31.68
1.055	7.4	11	11.18	39.73	34.82
1.060	8.0	12	12.19	43.32	37.97
1.065	8.7	13	13.19	46.87	41.09
1.070	9.4	14	14.17	50.35	44.14
1.075	10.0	15	15.16	53.87	47.22
1.080	10.6	16	16.15	57.39	50.31
1.085	11.2	17	17.13	60.87	53.36
1.090	11.9	18	18.11	64.35	56.41
1.095	12.4	19	19.06	67.73	59.37
1.100	13.0	20	20.01	71.11	62.33
1.105	13.6	21	20.97	74.52	65.32
1.110	14.2	22	21.92	77.89	68.28
1.115	14.9	23	22.86	81.23	71.21
1.120	15.4	24	23.82	84.64	74.20
1.125	16.0	25	24.78	88.06	77.19
1.130	16.5	26	25.75	91.50	80.21
1.135	17.1	27	26.70	94.88	83.18
1.140	17.7	28	27.66	98.29	86.17
1.145	18.3	29	28.61	101.67	87.66
1.150	18.8	30	29.57	105.08	92.11
1.155	19.3	31	30.55	108.58	95.17
1.160	19.8	32	31.52	112.01	98.19
1.165	20.3	33	32.49	115.46	101.21
1.170	20.9	34	33.46	118.91	104.24
1.175	21.4	35	34.42	122.32	107.22
1.180	22.0	36	35.39	125.76	110.24
1.185	22.5	37	36.31	129.03	131.11
1.190	23.0	38	37.23	132.30	115.98
1.195	23.5	39	38.16	135.61	118.87
1.200	24.0	40	39.11	138.98	121.84

This table is taken from Lunge. Other authorities giving in one case as much as 40.78 per cent. of HCl sp. gr. acid.

SPECIFIC GRAVITY OF NITRIC ACID AT 15°, COMPARED WITH WATER AT 4°

Sp. gr. $\frac{15°}{4°}$	Degrees Baumé	Degrees Twaddell	100 parts of acid contain by weight				
			N_2O_5	HNO_3	38° acid	40° acid	48.5° acid
1.000	0.0	0	0.08	0.10	0.19	0.16	0.10
1.005	0.7	1	0.85	1.00	1.89	1.61	1.03
1.010	1.4	2	1.62	1.90	3.60	3.07	1.95
1.015	2.1	3	2.39	2.80	5.30	4.52	2.87
1.020	2.7	4	3.17	3.70	7.01	5.98	3.79
1.025	3.4	5	3.94	4.60	8.71	7.43	4.72
1.030	4.1	6	4.71	5.50	10.42	8.88	5.64
1.035	4.7	7	5.47	6.38	12.08	10.30	6.54
1.040	5.4	8	6.22	7.26	13.75	11.72	7.45
1.045	6.0	9	6.97	8.13	15.40	13.13	8.34
1.050	6.7	10	7.71	8.99	17.03	14.52	9.22
1.055	7.4	11	8.43	9.84	18.64	15.89	10.09
1.060	8.0	12	9.15	10.68	20.23	17.25	10.95
1.065	8.7	13	9.87	11.51	21.80	18.59	11.81
1.070	9.4	14	10.57	12.33	23.35	19.91	12.65
1.075	10.0	15	11.27	13.15	24.91	21.24	13.49
1.080	10.6	16	11.96	13.95	26.42	22.53	14.31
1.085	11.2	17	12.64	14.74	27.92	23.80	15.12
1.090	11.9	18	13.31	15.53	29.41	25.08	15.93
1.095	12.4	19	13.99	16.32	30.91	26.35	16.74
1.100	13.0	20	14.67	17.11	32.41	27.63	17.55
1.105	13.6	21	15.34	17.89	33.89	28.89	18.35
1.110	14.2	22	16.00	18.67	35.36	30.15	19.15
1.115	14.9	23	16.67	19.45	36.84	31.41	19.95
1.120	15.4	24	17.34	20.23	38.31	32.67	20.75
1.125	16.0	25	18.00	21.00	39.77	33.91	21.54
1.130	16.5	26	18.66	21.77	41.23	35.16	22.23
1.135	17.1	27	19.32	22.54	42.69	36.40	23.12
1.140	17.7	28	19.98	23.31	44.15	37.65	23.91
1.145	18.3	29	20.64	24.08	45.61	38.89	24.70
1.150	18.8	30	21.29	24.84	47.05	40.12	25.48
1.155	19.3	31	21.94	25.60	48.49	41.35	26.26
1.160	19.8	32	22.60	26.36	49.92	42.57	27.04
1.165	20.3	33	23.25	27.12	51.36	43.80	27.82
1.170	20.9	34	23.90	27.88	52.80	45.03	28.59
1.175	21.4	35	24.54	28.63	54.22	46.24	29.36
1.180	22.0	36	25.18	29.38	55.64	47.45	30.13

SPECIFIC GRAVITY OF NITRIC ACID AT 15° COMPARED WITH WATER AT 4°. *Continued*

Sp. gr., $\frac{15°}{4°}$	Degrees Baumé	Degrees Twaddell	100 parts of acid contain by weight				
			N_2O_5	HNO_3	38° acid	40° acid	48.5° acid
1.185	22.5	37	25.83	30.13	57.07	48.66	30.90
1.190	23.0	38	26.47	30.88	58.49	49.87	31.67
1.195	23.5	39	27.10	31.62	59.89	51.07	32.43
1.200	24.0	40	27.74	32.36	61.29	52.26	33.19
1.205	24.5	41	28.36	33.09	62.67	53.23	33.94
1.210	25.0	42	28.99	33.82	64.05	54.21	34.69
1.215	25.5	43	29.61	34.55	65.44	55.18	35.44
1.220	26.0	44	30.24	35.28	66.82	56.16	36.18
1.225	26.4	45	30.88	36.03	68.24	57.64	36.95
1.230	26.9	46	31.53	36.78	69.66	59.13	37.72
1.235	27.4	47	32.17	37.53	71.08	60.61	38.49
1.240	27.9	48	32.82	38.29	72.52	61.84	39.27
1.245	28.4	49	33.47	39.05	73.96	63.07	40.05
1.250	28.8	50	34.13	39.82	75.42	64.31	40.84
1.255	29.3	51	34.78	40.58	76.86	65.54	41.62
1.260	29.7	52	35.44	41.34	78.30	66.76	42.40
1.265	30.2	53	36.09	42.10	79.74	67.99	43.18
1.270	30.6	54	36.75	42.87	81.20	69.23	43.97
1.275	31.1	55	37.41	43.64	82.65	70.48	44.76
1.280	31.5	56	38.07	44.41	84.11	71.72	45.55
1.285	32.0	57	38.73	45.18	85.57	72.96	46.34
1.290	32.4	58	39.39	45.95	87.03	74.21	47.13
1.295	32.8	59	40.05	46.72	88.48	75.45	47.92
1.300	33.3	60	40.71	47.49	89.94	76.70	48.71
1.305	33.7	61	41.37	48.28	91.40	77.94	49.50
1.310	34.2	62	42.06	49.07	92.94	79.25	50.33
1.315	34.6	63	42.76	49.89	94.49	80.57	51.17
1.320	35.0	64	43.47	50.71	96.05	81.90	52.01
1.325	35.4	65	44.17	51.53	97.60	83.22	52.85
1.330	35.8	66	44.89	52.37	99.19	84.58	53.71
1.335	36.2	67	45.62	53.22	100.80	85.95	54.58
1.340	36.6	68	46.35	54.07	102.41	87.32	55.46
1.345	37.0	69	47.08	54.93	104.04	88.71	56.34
1.350	37.4	70	47.82	55.79	105.67	90.10	57.22
1.355	37.8	71	48.57	56.66	107.31	91.51	58.11

Specific Gravity of Nitric Acid at 15° Compared with Water at 4°. *Continued*

Sp. gr., $\frac{15°}{4°}$	Degrees Baumé	Degrees Twaddell	100 parts of acid contain by weight				
			N_2O_5	HNO_3	38° acid	40° acid	48.5° acid
1.360	38.2	72	49.35	57.57	109.03	92.97	59.05
1.365	38.6	73	50.13	58.48	110.75	94.44	59.98
1.370	39.0	74	50.91	59.39	112.48	95.91	60.91
1.375	39.4	75	51.69	60.30	114.20	97.38	61.85
1.380	39.8	76	52.52	61.27	116.04	98.95	62.84
1.385	40.1	77	53.35	62.24	117.88	100.51	63.84
1.390	40.5	78	54.20	63.23	119.75	102.12	64.85
1.395	40.8	79	55.07	64.25	121.68	103.76	65.90
1.400	41.2	80	55.97	65.30	123.67	105.46	66.97
1.405	41.6	81	56.92	66.40	125.75	107.24	68.10
1.410	42.0	82	57.86	67.50	127.84	109.01	69.23
1.415	42.3	83	58.83	68.63	129.98	110.84	70.39
1.420	42.7	84	59.83	69.80	132.19	112.73	71.59
1.425	43.1	85	60.84	70.98	134.43	114.63	72.80
1.430	43.4	86	61.86	72.17	136.68	116.55	74.02
1.435	43.8	87	62.91	73.39	138.99	118.52	75.27
1.440	44.1	88	64.01	74.68	141.44	120.61	76.59
1.445	44.4	89	65.13	75.98	143.90	122.71	77.93
1.450	44.8	90	66.24	77.28	146.36	124.81	79.26
1.455	45.1	91	67.38	78.60	148.86	126.94	80.62
1.460	45.4	92	68.56	79.98	151.47	129.17	82.03
1.465	45.8	93	69.79	81.42	154.20	131.49	83.51
1.470	46.1	94	71.06	82.90	157.00	133.88	85.03
1.475	46.4	95	72.39	84.45	159.04	136.39	86.62
1.480	46.8	96	73.76	86.05	162.97	138.97	88.26
1.485	47.1	97	75.13	87.70	166.09	141.63	89.95
1.490	47.4	98	76.80	89.60	169.69	144.70	91.90
1.495	47.8	99	78.52	91.60	173.48	147.93	93.95
1.500	48.1	100	80.65	94.09	178.19	151.99	96.50
1.505	48.4	101	82.63	96.39	182.55	155.67	98.86
1.510	48.7	102	84.09	98.10	185.79	158.43	100.62
1.515	49.0	103	84.92	99.07	187.63	160.00	101.61
1.520	49.4	104	85.44	99.67	188.77	160.97	102.23

Specific Gravity of Ammonia Water at 15°C. Co WITH Water of 15°C.

Spr. gr. $\frac{15^\circ}{15^\circ}$	Per cent. NH_4OH	Correction to sp. gr. for ±1°C.	Sp. gr. $\frac{15^\circ}{15^\circ}$	Per cent. NH_4OH	Cor to sp ±
1.000	0.00	0.00018	0.940	15.63	0.
0.998	0.45	0.00018	0.938	16.22	0.
0.996	0.91	0.00019	0.936	16.82	0.
0.994	1.37	0.00019	0.934	17.42	0.
0.992	1.84	0.00020	0.932	18.03	0.
0.990	2.31	0.00020	0.930	18.64	0.
0.988	2.80	0.00021	0.928	19.25	0.
0.986	3.30	0.00021	0.926	19.87	0.
0.984	3.80	0.00022	0.924	20.49	0.
0.982	4.30	0.00022	0.922	21.12	0.
0.980	4.80	0.00023	0.920	21.75	0.
0.978	5.30	0.00023	0.918	22.39	0.
0.976	5.80	0.00024	0.916	23.03	0.
0.974	6.30	0.00024	0.914	23.68	0.
0.972	6.80	0.00025	0.912	24.33	0.
0.970	7.31	0.00025	0.910	24.99	0.
0.968	7.82	0.00026	0.908	25.65	0.
0.966	8.33	0.00026	0.906	26.31	0.
0.964	8.84	0.00027	0.904	26.98	0.
0.962	9.35	0.00028	0.902	27.65	0.
0.960	9.91	0.00029	0.900	28.33	0.
0.958	10.47	0.00030	0.898	29.01	0.
0.956	11.03	0.00031	0.896	29.69	0.
0.954	11.60	0.00032	0.894	30.37	0.
0.952	12.17	0.00033	0.892	31.05	0.
0.950	12.74	0.00034	0.890	31.75	0.
0.948	13.31	0.00035	0.888	32.50	0.
0.946	13.88	0.00036	0.886	33.25	0.
0.944	14.46	0.00037	0.884	34.10	0.
0.942	15.04	0.00038	0.882	34.95	0.

This and the nitric-acid table immediately preceding are reprinted by of the D. van Nostrand Co., New York, from Lunge's "Sulphuric A Alkali."

Specific Gravity of Caustic Potash Solutions at 15°C.[1]

(Grams KOH per 100 grams solution)

Sp. gr.	Per cent., KOH	Sp. gr.	Per cent., KOH	Sp. gr.	Per cent., KOH
1.036	5	1.288	30	1.604	55
1.077	10	1.349	35	1.667	60
1.124	15	1.411	40	1.729	65
1.175	20	1.475	45	1.790	70
1.230	25	1.539	50	....	....

[1] This and the succeeding 14 tables are from Cremer & Bicknell's *Chemical and Metallurgical Handbook*. They are originally from the work of Kohlrausch and Holborn, Gerlach, Schiff, etc.

Specific Gravity of Caustic Soda Solutions at 15°C.

Sp. gr.	Per cent., NaOH	Sp. gr.	Per cent., NAOH	Sp. gr.	Per cent., NaOH
1.059	5	1.332	30	1.591	55
1.115	10	1.384	35	1.643	60
1.170	15	1.437	40	1.695	65
1.225	20	1.488	45	1.748	70
1.279	25	1.540	50	....	....

Specific Gravity of Hydrofluosilicic Acid at 15°C.

Sp. gr.	Per cent., H_2SiF_6	Sp. gr.	Per cent., H_2SiF_6	Sp. gr.	Per cent., H_2SiF_6
1.0407	5	1.1748	20	1.2742	30
1.0834	10	1.2235	25	1.3162	34
1.1281	15				

Specific Gravity of Sodium Chloride Solutions at 15°C.

Sp. gr.	Per cent., NaCl	Sp. gr.	Per cent., NaCl	Sp. gr.	Per cent., NaCl
1.00725	1	1.07335	10	1.14351	19
1.01450	2	1.08097	11	1.15107	20
1.02174	3	1.08859	12	1.15931	21
1.02899	4	1.09522	13	1.16755	22
1.03624	5	1.10384	14	1.17580	23
1.04366	6	1.11146	15	1.18404	24
1.05108	7	1.11938	16	1.19228	25
1.05851	8	1.12730	17	1.20098	26
1.06593	9	1.13523	18	1.20433	26.395[1]

[1] (Sat.)

Specific Gravity of Calcium Chloride Solutions at 15°C

Sp. gr.	Per cent., $CaCl_2$	Sp. gr.	Per cent., $CaCl_2$	Sp. gr.	Per cent., $CaCl_2$
1.01704	2	1.14332	16	1.28789	30
1.03407	4	1.16277	18	1.31045	32
1.05146	6	1.18222	20	1.33302	34
1.06921	8	1.20279	22	1.35610	36
1.08695	10	1.22336	24	1.37970	38
1.10561	12	1.24450	26	1.40330	40
1.12427	14	1.26619	28	1.41104	46.46

Specific Gravity of Zinc Chloride at 19.5°C.

Sp. gr.	Per cent., $ZnCl_2$	Sp. gr.	Per cent., $ZnCl_2$	Sp. gr.	Per cent., $ZnCl_2$
1.045	5	1.238	25	1.488	45
1.091	10	1.291	30	1.566	50
1.137	15	1.352	35	1.650	55
1.187	20	1.420	40	1.740	60

Specific Gravity of Ferric Chloride Solutions at 17.5°C

Sp. gr.	Per cent., $FeCl_3$	Sp. gr.	Per cent., $FeCl_3$	Sp. gr.	Per cent., $FeCl_3$
1.0146	2	1.1746	22	1.3870	42
1.0292	4	1.1950	24	1.4118	44
1.0439	6	1.2155	26	1.4367	46
1.0587	8	1.2365	28	1.4617	48
1.0734	10	1.2568	30	1.4867	50
1.0894	12	1.2778	32	1.5153	52
1.1054	14	1.2988	34	1.5439	54
1.1215	16	1.3199	36	1.5729	56
1.1378	18	1.3411	38	1.6023	58
1.1542	20	1.3622	40	1.6317	60

Specific Gravity of Cuprous Chloride Solutions at 17.5°C

Sp. gr.	Per cent., $CuCl_2$	Sp. gr.	Per cent., $CuCl_2$	Sp. gr.	Per cent., $CuCl_2$
1.0182	2	1.1696	16	1.3618	30
1.0364	4	1.1958	18	1.3950	32
1.0548	6	1.2223	20	1.4287	34
1.0734	8	1.2501	22	1.4615	36
1.0920	10	1.2779	24	1.4949	38
1.1178	12	1.3058	26	1.5284	40
1.1436	14	1.3338	28	....	....

Specific Gravity of Lead Acetate Solutions at 15°C.

Sp. gr.	Per cent., PbA_2	Sp. gr.	Per cent., PbA_2	Sp. gr.	Per cent., PbA_2
1.0127	2	1.1384	20	1.2967	38
1.0255	4	1.1544	22	1.3163	40
1.0386	6	1.1704	24	1.3376	42
1.0520	8	1.1869	26	1.3588	44
1.0654	10	1.2040	28	1.3810	46
1.0796	12	1.2211	30	1.4041	48
1.0939	14	1.2395	32	1.4271	50
1.1084	16	1.2578	34	....	....
1.1234	18	1.2768	36	....	....

Specific Gravity of Ferric Sulphate Solutions at 17.5°C.

Sp. gr.	Per cent., $Fe_2(SO_4)_3$	Sp. gr.	Per cent., $Fe_2(SO_4)_3$	Sp. gr.	Per cent., $Fe_2(SO_4)_3$
1.0170	2	1.2066	22	1.4824	42
1.0340	4	1.2306	24	1.5142	44
1.0512	6	1.2559	26	1.5468	46
1.0684	8	1.2825	28	1.5808	48
1.0854	10	1.3090	30	1.6148	50
1.1042	12	1.3368	32	1.6508	52
1.1230	14	1.3646	34	1.6868	54
1.1424	16	1.3927	36	1.7241	56
1.1624	18	1.4217	38	1.7623	58
1.1826	20	1.4506	40	1.8006	60

Specific Gravity of $FeSO_4 \cdot 7H_2O$; $CuSO_4 \cdot 5H_2O$ and $ZnSO_4 \cdot 7H_2O$ Solutions at 15°C.

Sp. gr.	Per cent., $ZnSO_4 \cdot 7H_2O$	Sp. gr.	Per cent., $CuSO_4 \cdot 5H_2O$	Sp. gr.	Per cent., $FeSO_4 \cdot 7H_2O$
1.0288	5	1.0126	2	1.011	2
1.0593	10	1.0254	4	1.021	4
1.0905	15	1.0384	6	1.032	6
1.1236	20	1.0516	8	1.043	8
1.1574	25	1.0649	10	1.054	10
1.1933	30	1.0785	12	1.065	12
1.2310	35	1.0923	14	1.082	15
1.2709	40	1.1063	16	1.112	20
1.3100	45	1.1208	18	1.143	25
1.3522	50	1.1354	20	1.174	30
1.3986	55	1.1501	22	1.206	35
1.4451	60	1.1659	24	1.239	40

Specific Gravity of Sodium Carbonate Solutions at 15°C.

Sp. gr.	Per cent., Na_2CO_3	Sp. gr.	Per cent., Na_2CO_3	Sp. gr.	Per cent., Na_2CO_3
1.01050	1	1.06309	6	1.11655	11
1.02101	2	1.07369	7	1.12740	12
1.03151	3	1.08430	8	1.13845	13
1.04201	4	1.09500	9	1.14950	14
1.05255	5	1.10571	10	1.15360	14.354

Specific Gravity of Dihydrogen Sodium Arsenate Solutions at 17°C.

Sp. gr.	Per cent., $H_2NaAsO_4 \cdot H_2O$	Sp. gr.	Per cent., $H_2NaAsO_4 \cdot H_2O$
1.0226	4.22	1.9038	16.88
1.0460	8.44	1.1186	21.10
1.0577	10.55	....	....

Specific Gravity of Solutions of Trisodium Arsenate at 17°C.

Sp. gr.	$Na_3AsO_4 \cdot 12H_2O$	Sp. gr.	$Na_3AsO_4 \cdot 12H_2O$
1.0193	4.40	1.0812	17.60
1.0393	8.80	1.1035	22.06
1.0495	11.00	....	....

Specific Gravity of Disodium Arsenate Solutions at 14°C.

1.0169	4	1.0714	16
1.0344	8	1.1102	23.9
1.0525	12	1.1722	35.9

Densities of Some Saline and Acid Solutions[1]

Substances	Temperatures	Percentage of salt					
		5	10	20	30	40	60
Potassium chloride	15.0°C.	1.031	1.065	1.135	.....	.....	.....
Ammonium chloride	15.0°C.	1.015	1.030	1.058	.....	.....	.....
Sodium bromide	19.5°C.	1.038	1.078	1.172	1.279	1.407	.....
Potassium bromide	19.5°C.	1.035	1.073	1.157	1.253	.....	.....
Potassium iodide	19.5°C.	1.036	1.076	1.164	1.269	1.393	1.730
Sodium nitrate	20.2°C.	1.031	1.066	1.140	1.222	1.313	.....
Potassium nitrate	15.0°C.	1.031	1.064	1.135	.....	.....	.....
Ammonium nitrate	17.5°C.	1.020	1.042	1.086	1.131	1.179	1.283
Silver nitrate	15.0°C.	1.042	1.089	1.196	1.321	1.476	1.916
Potassium carbonate	15.0°C.	1.044	1.092	1.192	1.300	1.417	.....
Magnesium sulphate	15.0°C.	1.053	1.107	1.213	.....	.....	.....
Sodium sulphate	18.0°C.	1.045	1.091	.....	.....	.....	.....
Potassium bichromate	19.5°C.	1.034	1.071	.....	.....	.....	.....
Potassium ferricyanide	13.0°C.	1.025	1.053	1.113	.....	.....	.....
Hydrobromic acid	14.0°C.	1.033	1.072	1.157	1.255	.....	.....
Hydriodic acid	13.0°C.	1.036	1.076	1.164	1.269	1.347	.....
Phosphoric acid	15.0°C.	1.026	1.055	1.118	1.180	1.253	1.420

[1] "Annuaire pour 1914, Bureau des Longitudes."

BOILING POINTS

Boiling Points of the Metals

	Visible ebullition	Volatilization commences		Visible ebullition	Volatilization commences
Antimony	1420°C.[2]	....	Osmium	2950°C.[5]	....
Aluminum	1800°C.[2]	....	Palladium	2540°C.[5]	....
Bismuth	1440°C.[2]	....	Platinum	2650°C.[5]	....
Chromium	2200°C.[2]	1420°C.[3]	Rhodium	2750°C.[5]	....
Copper[1]	2310°C.[2]	960°C.[3]	Rubidium	696°C.	....
Gold	2100°C.[3]	970°C.[3]	Ruthenium	2780°C.[5]	....
Indium	1000°C.	....	Selenium	690°C.[6]	....
Iron	2450°C.[2]	....	Silicon	3800°C.[5]	1350°C.[3]
Iridium	2850°C.[5]	....	Silver	1955°C.[2]	850°C.
Lead	1525°C.[2]	....	Tantalum	....	2200°C.[3]
Lithium	500°C.[6]	....	Tellurium	1390°C.[6]	....
Magnesium	1120°C.[5]	....	Tin[7]	2275°C.[2]	880°C.[3]
Manganese	1900°C.[2]	1290°C.[3]	Titanium	2700°C.[5]	....
Mercury	357°C.[6]	....	Thallium	1280°C.(?)	....
Molybdenum	3350°C.[5]	....	Uranium	3100°C.[5]	....
Nickel	2450°C.[5]	....	Wolfram	3700°C.[5]	2450°C.[3]

[1] According to Tiede and Birnbräuer, copper boils at 2000°.
[2] According to H. C. Greenwood.
[3] According to Tiede and Birnbräuer, *Zeit. anorg. chem.*, 1914, p. 129.
[4] Dulong and Petit.
[5] Watts, *Tr. Electrochem. Soc.*, 1907, p. 141.
[6] Richards, "Metallurgical Calculations."
[7] Given by Carnelly as 1550°C.

	Beginning of evaporation *in vacuo*[1]	Boiling point *in vacuo*[1]	Boiling-point 760° mm.[1]
Bismuth	270°C.	993°C.	1440°C.
Cadmium	156	450	749
Mercury	−40	155	357
Potassium	63	365	667
Silver	680	1360	1955
Sodium	98	418	742
Zinc	184	550	920
Sulphur	....	....	444.5

[1] According to H. C. Greenwood.

Boiling Points of the Non-metallic Elements[1]

	Visible ebullition		Visible ebullition
Argon	− 186.0°C.	Hydrogen	− 252.7°C.
Arsenic sublimes	450.0°C.	Iodine	184.4°C.
Boron sublimes(?)	3500.0°C.	Krypton	− 151.7°C.
Bromine	63.0°C.	Neon	− 239.0°C.
Carbon	3700.0°C.	Nitrogen	− 195.7°C.
Chlorine	− 33.6°C.	Oxygen	− 182.9°C.
Fluorine	− 187.0°C.	Phosphorus	287.0°C.
Helium	− 268.6°C.	Xenon	− 109.0°C.

[1] J. W. Richards, "Metallurgical Calculations" and Kaye and Laby's "Physical and Chemical Constants."

Boiling Points of Some Common Compounds

Ammonia	− 29°F.
Carbon dioxide	− 112°F.
Sulphur dioxide	+ 14°F.
Water	212°F.

Boiling Point of Water under Various Barometric Pressures

Pressure mm. of mercury	0	1	2	3	4	5	6	7	8	9
	°C.									
680	96.91	96.95	97.00	97.03	97.07	97.11	97.15	97.20	97.24	97.28
690	97.32	97.36	97.40	97.44	97.48	97.52	97.56	97.59	97.63	97.67
700	97.71	97.75	97.79	97.83	97.87	97.91	97.95	97.99	98.03	98.07
710	98.11	98.14	98.18	98.22	98.26	98.30	98.34	98.38	98.42	98.45
720	98.49	98.53	98.57	98.61	98.65	98.69	98.72	98.76	98.80	98.84
730	98.88	98.91	98.95	98.99	99.03	99.07	99.10	99.14	99.18	99.22
740	99.25	99.29	99.33	99.37	99.41	99.44	99.48	99.52	99.56	99.59
750	99.63	99.67	99.70	99.74	99.78	99.81	99.85	99.89	99.93	99.96
760	100.00	100.03	100.07	100.11	100.15	100.18	100.22	100.26	100.29	100.33
770	100.37	100.40	100.44	100.47	100.51	100.55	100.58	100.62	100.66	100.69
780	100.73	100.76	100.80	100.84	100.87	100.91	100.94	100.98	101.01	101.05

Regnault gives slightly different values, as shown in the ɔllowing table:

BOILING POINT OF WATER AT DIFFERENT BAROMETER READINGS (REGNAULT)

Boiling point	Millimeters	Boiling point	Millimeters
100.4°C.	771.95	99.4°C.	743.83
100.3°	768.20	99.3°	741.16
100.2°	765.46	99.2°	738.50
100.1°	762.73	99.1°	735.85
100.0°	760.00	99.0°	733.21
99.9°	757.28	98.9°	730.58
99.8°	754.57	98.8°	727.96
99.7°	751.87	98.7°	725.35
99.6°	749.18	98.6°	722.75
99.5°	746.50	98.5°	720.15

BOILING POINTS OF NITRIC ACID SOLUTIONS IN WATER[1]
(160 mm. pressure)

Per cent., HNO_3	Boiling point, degrees C.	Per cent., HNO_3	Boiling point, degrees C.
19.37	103.56	67.74	121.67
30.43	108.08	68.18	121.79
41.38	112.59	69.24	121.80
51.63	116.85	71.10	121.60
56.01	118.88	73.56	120.75
59.77	120.06	80.50	115.45
63.89	121.27	85.51	108.12
65.17	121.66	90.06	102.03
....	....	95.45	95.42

[1] CREIGHTON and GITHENS, "Journal of the Franklin Institute," Febɪary, 1915.

EQUIVALENT EVAPORATION FROM AND AT 212 DEGREES[1]

Temperature of feed water, degrees F.	Pressure of steam in pounds absolute—dry saturated											Temperature of feed water, degrees F.
	15	25	35	45	55	65	75	85	95	105	115	125	
32	1.1858	1.1958	1.2024	1.2073	1.2113	1.2144	1.2171	1.2195	1.2216	1.2234	1.2251	1.2266	32
35	1.1827	1.1927	1.1993	1.2042	1.2081	1.2113	1.2140	1.2164	1.2184	1.2203	1.2219	1.2235	35
40	1.1775	1.1875	1.1941	1.1990	1.2030	1.2062	1.2088	1.2112	1.2133	1.2151	1.2168	1.2183	40
45	1.1723	1.1823	1.1889	1.1939	1.1978	1.2010	1.2037	1.2060	1.2081	1.2099	1.2116	1.2131	45
50	1.1672	1.1772	1.1838	1.1887	1.1926	1.1958	1.1985	1.2009	1.2029	1.2048	1.2064	1.2080	50
55	1.1620	1.1720	1.1786	1.1836	1.1875	1.1907	1.1933	1.1957	1.1978	1.1996	1.2013	1.2028	55
60	1.1569	1.1669	1.1735	1.1784	1.1823	1.1855	1.1882	1.1906	1.1926	1.1945	1.1961	1.1977	60
65	1.1517	1.1617	1.1683	1.1733	1.1772	1.1804	1.1830	1.1854	1.1875	1.1893	1.1910	1.1925	65
70	1.1466	1.1566	1.1632	1.1681	1.1720	1.1752	1.1779	1.1803	1.1823	1.1842	1.1858	1.1874	70
75	1.1414	1.1514	1.1580	1.1630	1.1669	1.1701	1.1728	1.1751	1.1772	1.1790	1.1807	1.1823	75
80	1.1363	1.1463	1.1529	1.1578	1.1618	1.1650	1.1676	1.1700	1.1721	1.1739	1.1756	1.1771	80
85	1.1312	1.1412	1.1478	1.1527	1.1566	1.1598	1.1625	1.1649	1.1669	1.1688	1.1704	1.1720	85
90	1.1260	1.1360	1.1426	1.1476	1.1515	1.1547	1.1574	1.1597	1.1618	1.1636	1.1653	1.1668	90
95	1.1209	1.1309	1.1375	1.1424	1.1463	1.1495	1.1522	1.1546	1.1566	1.1585	1.1602	1.1617	95
100	1.1158	1.1258	1.1323	1.1373	1.1412	1.1444	1.1471	1.1495	1.1515	1.1534	1.1550	1.1566	100
105	1.1106	1.1206	1.1272	1.1322	1.1361	1.1393	1.1420	1.1443	1.1464	1.1482	1.1499	1.1516	105
110	1.1055	1.1155	1.1221	1.1270	1.1309	1.1341	1.1368	1.1392	1.1412	1.1431	1.1447	1.1463	110
115	1.1004	1.1103	1.1169	1.1219	1.1258	1.1290	1.1248	1.1341	1.1361	1.1380	1.1396	1.1412	115
120	1.0952	1.1052	1.1118	1.1167	1.1207	1.1239	1.1265	1.1289	1.1310	1.1328	1.1345	1.1360	120
125	1.0901	1.1001	1.1067	1.1116	1.1155	1.1187	1.1214	1.1238	1.1258	1.1277	1.1293	1.1309	125
130	1.0849	1.0949	1.1015	1.1065	1.1104	1.1136	1.1163	1.1186	1.1207	1.1225	1.1242	1.1257	130
135	1.0798	1.0898	1.0964	1.1013	1.1052	1.1084	1.1111	1.1135	1.1155	1.1174	1.1190	1.1206	135
140	1.0746	1.0846	1.0912	1.0962	1.1001	1.1033	1.1060	1.1083	1.1104	1.1123	1.1139	1.1154	140
145	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	145

165	1.0489	1.0589	1.0655	1.0704	1.0743	1.0775	1.0802	1.0826	1.0846	1.0865	1.0881	1.0897	165
170	1.0437	1.0537	1.0603	1.0653	1.0692	1.0724	1.0751	1.0774	1.0795	1.0813	1.0830	1.0845	170
171	1.0427	1.0527	1.0593	1.0642	1.0681	1.0713	1.0740	1.0764	1.0785	1.0803	1.0820	1.0835	171
172	1.0417	1.0517	1.0583	1.0632	1.0671	1.0703	1.0730	1.0754	1.0774	1.0793	1.0809	1.0825	172
173	1.0406	1.0506	1.0572	1.0622	1.0661	1.0693	1.0720	1.0743	1.0764	1.0782	1.0799	1.0814	173
174	1.0396	1.0496	1.0562	1.0611	1.0651	1.0683	1.0709	1.0733	1.0754	1.0772	1.0789	1.0804	174
175	1.0386	1.0486	1.0552	1.0601	1.0640	1.0672	1.0699	1.0723	1.0743	1.0762	1.0778	1.0793	175
176	1.0375	1.0475	1.0541	1.0591	1.0630	1.0662	1.0689	1.0712	1.0733	1.0752	1.0768	1.0783	176
177	1.0365	1.0465	1.0531	1.0580	1.0620	1.0651	1.0678	1.0702	1.0723	1.0741	1.0758	1.0773	177
178	1.0355	1.0455	1.0521	1.0570	1.0609	1.0641	1.0668	1.0692	1.0712	1.0731	1.0747	1.0763	178
179	1.0344	1.0444	1.0510	1.0560	1.0599	1.0631	1.0658	1.0681	1.0702	1.0721	1.0737	1.0752	179
180	1.0334	1.0434	1.0500	1.0549	1.0589	1.0621	1.0647	1.0671	1.0692	1.0710	1.0727	1.0742	180
181	1.0324	1.0424	1.0490	1.0539	1.0578	1.0610	1.0637	1.0661	1.0681	1.0700	1.0716	1.0732	181
182	1.0313	1.0413	1.0479	1.0529	1.0568	1.0600	1.0627	1.0650	1.0671	1.0690	1.0706	1.0721	182
183	1.0303	1.0403	1.0469	1.0518	1.0558	1.0590	1.0616	1.0640	1.0661	1.0679	1.0696	1.0711	183
184	1.0293	1.0393	1.0459	1.0508	1.0547	1.0579	1.0606	1.0630	1.0650	1.0669	1.0685	1.0701	184
185	1.0282	1.0382	1.0448	1.0498	1.0537	1.0569	1.0596	1.0619	1.0640	1.0659	1.0675	1.0691	185
186	1.0272	1.0372	1.0438	1.0488	1.0527	1.0559	1.0585	1.0609	1.0630	1.0648	1.0665	1.0680	186
187	1.0262	1.0362	1.0428	1.0477	1.0516	1.0548	1.0575	1.0599	1.0619	1.0638	1.0654	1.0670	187
188	1.0251	1.0351	1.0417	1.0467	1.0506	1.0538	1.0565	1.0588	1.0609	1.0628	1.0644	1.0660	188
189	1.0241	1.0341	1.0407	1.0457	1.0496	1.0528	1.0554	1.0578	1.0599	1.0617	1.0634	1.0649	189
190	1.0231	1.0331	1.0397	1.0446	1.0485	1.0517	1.0544	1.0568	1.0588	1.0607	1.0623	1.0639	190
191	1.0220	1.0320	1.0386	1.0436	1.0475	1.0507	1.0534	1.0557	1.0578	1.0597	1.0613	1.0629	191
192	1.0210	1.0310	1.0376	1.0425	1.0465	1.0497	1.0523	1.0547	1.0568	1.0586	1.0603	1.0618	192
193	1.0200	1.0300	1.0366	1.0415	1.0454	1.0486	1.0513	1.0537	1.0557	1.0576	1.0592	1.0608	193
194	1.0189	1.0289	1.0355	1.0405	1.0444	1.0476	1.0503	1.0526	1.0547	1.0566	1.0582	1.0597	194
195	1.0179	1.0279	1.0345	1.0394	1.0434	1.0466	1.0492	1.0516	1.0537	1.0555	1.0572	1.0587	195
196	1.0169	1.0269	1.0335	1.0384	1.0423	1.0455	1.0482	1.0506	1.0526	1.0545	1.0561	1.0577	196
197	1.0158	1.0258	1.0324	1.0374	1.0413	1.0445	1.0472	1.0495	1.0516	1.0535	1.0551	1.0566	197
198	1.0148	1.0248	1.0314	1.0363	1.0403	1.0435	1.0461	1.0485	1.0506	1.0524	1.0541	1.0556	198
199	1.0138	1.0238	1.0304	1.0353	1.0392	1.0424	1.0451	1.0475	1.0495	1.0514	1.0530	1.0546	199
200	1.0127	1.0227	1.0293	1.0343	1.0382	1.0414	1.0441	1.0464	1.0485	1.0504	1.0520	1.0535	200
201	1.0117	1.0217	1.0283	1.0332	1.0372	1.0404	1.0430	1.0454	1.0475	1.0493	1.0510	1.0525	201

[1] From "Power," Mar. 17, 1914.

EQUIVALENT EVAPORATION FROM AND AT 212 DEGREES. *Continued*

Temperature of feed water, degrees F.	Pressure of steam in pounds absolute—dry saturated												Temperatur of feed water, degrees F.
	15	25	35	45	55	65	75	85	95	105	115	125	
202	1.0107	1.0207	1.0273	1.0322	1.0361	1.0393	1.0420	1.0444	1.0464	1.0483	1.0499	1.0515	202
203	1.0096	1.0196	1.0262	1.0312	1.0351	1.0383	1.0410	1.0433	1.0454	1.0472	1.0489	1.0504	203
204	1.0086	1.0186	1.0252	1.0301	1.0340	1.0372	1.0399	1.0423	1.0444	1.0462	1.0479	1.0494	204
205	1.0076	1.0176	1.0242	1.0291	1.0330	1.0362	1.0389	1.0413	1.0433	1.0452	1.0468	1.0484	205
206	1.0065	1.0165	1.0231	1.0281	1.0320	1.0352	1.0379	1.0402	1.0423	1.0441	1.0458	1.0473	206
207	1.0055	1.0155	1.0221	1.0270	1.0309	1.0341	1.0368	1.0392	1.0413	1.0431	1.0448	1.0463	207
208	1.0045	1.0144	1.0210	1.0260	1.0299	1.0331	1.0358	1.0381	1.0402	1.0421	1.0437	1.0453	208
209	1.0034	1.0134	1.0200	1.0250	1.0289	1.0321	1.0347	1.0371	1.0392	1.0410	1.0427	1.0442	209
210	1.0024	1.0124	1.0190	1.0239	1.0278	1.0310	1.0337	1.0361	1.0381	1.0400	1.0416	1.0432	210
212	1.0003	1.0103	1.0169	1.0218	1.0258	1.0290	1.0316	1.0340	1.0361	1.0379	1.0396	1.0411	212
215	0.9972	1.0072	1.0138	1.0188	1.0227	1.0259	1.0285	1.0309	1.0330	1.0348	1.0365	1.0380	215
220	0.9920	1.0020	1.0086	1.0135	1.0174	1.0206	1.0233	1.0257	1.0277	2.0296	1.0312	1.0328	220
225	0.9868	0.9968	1.0034	1.0083	1.0123	1.0155	1.0181	1.0205	1.0226	1.0244	2.0261	1.0276	225
230	0.9816	0.9916	0.9981	1.0031	1.0070	1.0102	1.0129	1.0153	1.0173	1.0192	1.0208	1.0224	230
235	0.9764	0.9864	0.9930	0.9979	1.0019	1.0050	1.0077	1.0101	1.0122	1.0140	1.0157	1.0172	235
240	0.9711	0.9811	0.9877	0.9927	0.9966	0.9998	1.0025	1.0048	1.0069	1.0088	1.0104	1.0120	240
245	0.9660	0.9759	0.9825	0.9874	0.9913	0.9945	0.9972	0.9996	1.0016	1.0035	1.0052	1.0067	245
250	0.9606	0.9706	0.9772	0.9822	0.9861	0.9893	0.9920	0.9943	0.9964	0.9982	0.9999	1.0014	250
255	0.9555	0.9655	0.9721	0.9770	0.9809	0.9841	0.9868	0.9892	0.9912	0.9931	0.9947	0.9963	255
260	0.9502	0.9602	0.9668	0.9718	0.9757	0.9789	0.9816	0.9839	0.9860	0.9878	0.9895	0.9910	260
265	0.9450	0.9550	0.9616	0.9665	0.9704	0.9736	0.9763	0.9787	0.9807	0.9826	0.9842	0.9858	265
270	0.9397	0.9497	0.9563	0.9613	0.9652	0.9684	0.9710	0.9734	0.9755	0.9773	0.9790	0.9805	270
275	0.9345	0.9446	0.9511	0.9560	0.9599	0.9631	0.0658	0.0682	0.9702	0.9721	0.9737	0.9754	275
280	0.9292	0.9392	0.9458	0.9507	0.9547	0.9579	0.9605	0.9629	0.9650	0.9668	0.9685	0.9700	280
285	0.9238	0.9338	0.9404	0.9454	0.9493	0.9525	0.9552	0.9575	0.9596	0.9615	0.9631	0.9647	285

Equivalent Evaporation from and at 212 Degrees[1]

Temperature of feed water, degrees F.	Pressure of steam in pounds absolute—dry saturated												Temperature of feed water, degrees F.
	135	145	155	165	175	185	195	205	215	225	235	245	
32	1.2279	1.2292	1.2304	1.2315	1.2324	1.2333	1.2342	1.2351	1.2357	1.2365	1.2372	1.2378	32
35	1.2248	1.2261	1.2273	1.2283	1.2293	1.2302	1.2311	1.2319	1.2326	1.2334	1.2341	1.2347	35
40	1.2197	1.2209	1.2221	1.2232	1.2241	1.2250	1.2259	1.2268	1.2274	1.2282	1.2289	1.2295	40
45	1.2145	1.2157	1.2170	1.2180	1.2189	1.2198	1.2208	1.2216	1.2222	1.2230	1.2238	1.2244	45
50	1.2093	1.2106	1.2118	1.2128	1.2137	1.2147	1.2156	1.2164	1.2170	1.2179	1.2186	1.2192	50
55	1.2042	1.2054	1.2066	1.2077	1.2086	1.2095	1.2104	1.2113	1.2119	1.2127	1.2134	1.2141	55
60	1.1990	1.2002	1.2135	1.2025	1.2034	1.2044	1.2053	1.2061	1.2067	1.2076	1.2083	1.2089	60
65	1.1939	1.1951	1.1963	1.1974	1.1983	1.1992	1.2002	1.2010	1.2016	1.2024	1.2031	1.2038	65
70	1.1887	1.1900	1.1912	1.1922	1.1932	1.1941	1.1950	1.1958	1.1965	1.1973	1.1980	1.1986	70
75	1.1836	1.1848	1.1861	1.1871	1.1880	1.1889	1.1899	1.1907	1.1913	1.1921	1.1929	1.1935	75
80	1.1785	1.1797	1.1809	1.1820	1.1829	1.1838	1.1847	1.1856	1.1862	1.1870	1.1877	1.1883	80
85	1.1733	1.1745	1.1758	1.1768	1.1777	1.1787	1.1796	1.1804	1.1810	1.1819	1.1826	1.1832	85
90	1.1682	1.1694	1.1707	1.1717	1.1726	1.1735	1.1745	1.1753	1.1759	1.1767	1.1775	1.1781	90
95	1.1630	1.1643	1.1655	1.1665	1.1675	1.1684	1.1693	1.1701	1.1708	1.1716	1.1723	1.1729	95
100	1.1579	1.1591	1.1604	1.1614	1.1623	1.1633	1.1642	1.1650	1.1657	1.1665	1.1672	1.1678	100
105	1.1528	1.1540	1.1552	1.1563	1.1572	1.1581	1.1591	1.1599	1.1606	1.1613	1.1620	1.1627	105
110	1.1476	1.1489	1.1501	1.1511	1.1521	1.1530	1.1539	1.1547	1.1553	1.1562	1.1569	1.1575	110
115	1.1425	1.1437	1.1450	1.1460	1.1469	1.1479	1.1488	1.1496	1.1503	1.1511	1.1518	1.1524	115
120	1.1374	1.1386	1.1398	1.1409	1.1418	1.1427	1.1436	1.1445	1.1452	1.1459	1.1466	1.1472	120
125	1.1322	1.1335	1.1347	1.1357	1.1366	1.1376	1.1385	1.1393	1.1400	1.1408	1.1415	1.1421	125
130	1.1271	1.1283	1.1295	1.1306	1.1315	1.1324	1.1334	1.1342	1.1349	1.1356	1.1363	1.1370	130
135	1.1219	1.1232	1.1244	1.1254	1.1264	1.1273	1.1282	1.1290	1.1298	1.1305	1.1312	1.1318	135
140	1.1168	1.1180	1.1193	1.1203	1.1212	1.1221	1.1231	1.1239	1.1246	1.1253	1.1261	1.1267	140
145	1.1116	1.1129	1.1141	1.1151	1.1161	1.1170	1.1179	1.1188	1.1195	1.1202	1.1209	1.1215	145
150	1.1065	1.1077	1.1090	1.1100	1.1109	1.1119	1.1128	1.1136	1.1143	1.1150	1.1158	1.1164	150
155	1.1013	1.1026	1.1038	1.1048	1.1058	1.1067	1.1076	1.0185	1.1092	1.1099	1.1106	1.1112	155
160	1.0962	1.0974	1.0987	1.0997	1.1006	1.1015	1.1025	1.1033	1.1040	1.1047	1.1055	1.1061	160

[1] From "Power," Mar. 17, 1914.

EQUIVALENT EVAPORATION FROM AND AT 212 DEGREES. *Continued*

Temperature of feed water, degrees F.	Pressure of steam in pounds absolute—dry saturated												Temperature of feed water, degrees F.
	135	145	155	165	175	185	195	205	215	225	235	245	
165	1.0910	1.0923	1.0935	1.0945	1.0955	1.0964	1.0973	1.0981	1.0989	1.0996	1.1003	1.1009	165
170	1.0859	1.0871	1.0883	1.0894	1.0903	1.0912	1.0922	1.0930	1.0937	1.0944	1.0951	1.0958	170
171	1.0848	1.0861	1.0873	1.0883	1.0893	1.0902	1.0911	1.0920	1.0927	1.0934	1.0941	1.0947	171
172	1.0838	1.0850	1.0863	1.0873	1.0882	1.0892	1.0901	1.0909	1.0916	1.0924	1.0931	1.0937	172
173	1.0828	1.0840	1.0853	1.0863	1.0872	1.0881	1.0891	1.0899	1.0906	1.0913	1.0921	1.0927	173
174	1.0817	1.0830	1.0842	1.0853	1.0862	1.0871	1.0880	1.0889	1.0896	1.0903	1.0910	1.0916	174
175	1.0807	1.0820	1.0832	1.0842	1.0852	1.0861	1.0870	1.0878	1.0886	1.0893	1.0900	1.0906	175
176	1.0797	1.0809	1.0822	1.0832	1.0841	1.0850	1.0860	1.0868	1.0875	1.0882	1.0890	1.0896	176
177	1.0786	1.0799	1.0811	1.0822	1.0831	1.0840	1.0849	1.0858	1.0865	1.0872	1.0879	1.0885	177
178	1.0776	1.0789	1.0801	1.0811	1.0820	1.0830	1.0839	1.0847	1.0854	1.0862	1.0869	1.0875	178
179	1.0766	1.0778	1.0791	1.0801	1.0810	1.0819	1.0829	1.0837	1.0844	1.0851	1.0859	1.0865	179
180	1.0756	1.0768	1.0780	1.0791	1.0800	1.0809	1.0818	1.0827	1.0834	1.0841	1.0848	1.0854	180
181	1.0745	1.0758	1.0770	1.0780	1.0790	1.0799	1.0808	1.0816	1.0824	1.0831	1.0838	1.0844	181
182	1.0735	1.0747	1.0760	1.0770	1.0779	1.0788	1.0798	1.0806	1.0813	1.0820	1.0828	1.0834	182
183	1.0725	1.0737	1.0749	1.0760	1.0769	1.0778	1.0787	1.0796	1.0803	1.0810	1.0817	1.0823	183
184	1.0714	1.0727	1.0739	1.0749	1.0759	1.0768	1.0777	1.0785	1.0793	1.0800	1.0807	1.0813	184
185	1.0704	1.0716	1.0729	1.0739	1.0748	1.0758	1.0767	1.0775	1.0782	1.0789	1.0797	1.0803	185
186	1.0694	1.0706	1.0718	1.0729	1.0738	1.0747	1.0756	1.0765	1.0772	1.0779	1.0786	1.0793	186
187	1.0683	1.0696	1.0708	1.0718	1.0728	1.0737	1.0746	1.0754	1.0762	1.0769	1.0776	1.0782	187
188	1.0673	1.0685	1.0698	1.0708	1.0717	1.0727	1.0736	1.0744	1.0751	1.0758	1.0766	1.0772	188
189	1.0663	1.0675	1.0687	1.0698	1.0707	1.0716	1.0725	1.0734	1.0741	1.0748	1.0755	1.0762	189
190	1.0652	1.0665	1.0677	1.0687	1.0697	1.0706	1.0715	1.0723	1.0731	1.0738	1.0745	1.0751	190
191	1.0642	1.0654	1.0667	1.0677	1.0686	1.0695	1.0705	1.0713	1.0720	1.0727	1.0735	1.0741	191
192	1.0632	1.0644	1.0656	1.0667	1.0676	1.0685	1.0694	1.0703	1.0710	1.0717	1.0724	1.0731	192
193	1.0621	1.0634	1.0646	1.0656	1.0666	1.0675	1.0684	1.0692	1.0700	1.0707	1.0714	1.0720	193
194	1.0611	1.0623	1.0636	1.0646	1.0655	1.0664	1.0674	1.0682	1.0689	1.0696	1.0704	1.0710	194
195	1.0601	1.0613	1.0625	1.0636	1.0645	1.0654	1.0663	1.0672	1.0679	1.0686	1.0693	1.0700	195

196	**1.0590**	**1.0603**	**1.0615**	**1.0625**	**1.0635**	**1.0644**	**1.0653**	**1.0661**	**1.0669**	**1.0676**	**1.0683**	**1.0689**	**196**
197	1.0580	1.0592	1.0605	1.0615	1.0624	1.0633	1.0643	1.0651	1.0658	1.0665	1.0673	1.0679	197
198	1.0570	1.0582	1.0594	1.0605	1.0614	1.0623	1.0632	1.0641	1.0648	1.0655	1.0662	1.0668	198
199	1.0559	1.0572	1.0584	1.0594	1.0603	1.0613	1.0622	1.0630	1.0637	1.0645	1.0652	1.0658	199
200	1.0549	1.0561	1.0574	1.0584	1.0593	1.0602	1.0612	1.0620	1.0627	1.0634	1.0642	1.0648	200
201	1.0539	1.0551	1.0563	1.0574	1.0584	1.0592	1.0601	1.0610	1.0617	1.0624	1.0631	1.0637	201
202	1.0528	1.0541	1.0553	1.0563	1.0572	1.0582	1.0591	1.0599	1.0606	1.0614	1.0621	1.0627	202
203	1.0518	1.0530	1.0543	1.0553	1.0562	1.0571	1.0581	1.0589	1.0596	1.0603	1.0611	1.0617	203
204	1.0507	1.0520	1.0532	1.0542	1.0552	1.0561	1.0570	1.0579	1.0586	1.0593	1.0600	1.0606	204
205	1.0497	1.0509	1.0522	1.0532	1.0541	1.0551	1.0560	1.0568	1.0575	1.0583	1.0590	1.0596	205
206	1.0487	1.0499	1.0511	1.0522	1.0531	1.0540	1.0550	1.0558	1.0565	1.0572	1.0579	1.0586	206
207	1.0476	1.0489	1.0501	1.0511	1.0521	1.0530	1.0539	1.0548	1.0555	1.0562	1.0569	1.0575	207
208	1.0466	1.0478	1.0491	1.0501	1.0510	1.0520	1.0529	1.0537	1.0544	1.0552	1.0559	1.0565	208
209	1.0456	1.0468	1.0480	1.0491	1.0500	1.0509	1.0519	1.0527	1.0534	1.0541	1.0548	1.0555	209
210	1.0445	1.0458	1.0470	1.0480	1.0490	1.0499	1.0508	1.0516	1.0524	1.0531	1.0538	1.0544	210
212	1.0425	1.0437	1.0449	1.0460	1.0469	1.0478	1.0487	1.0496	1.0503	1.0510	1.0517	1.0523	212
215	1.0394	1.0406	1.0418	1.0429	1.0438	1.0447	1.0457	1.0465	1.0472	1.0479	1.0486	1.0493	215
220	1.0341	1.0353	1.0366	1.0376	1.0385	1.0395	1.0404	1.0412	1.0419	1.0427	1.0434	1.0440	220
225	1.0290	1.0302	1.0314	1.0325	1.0334	1.0343	1.0352	1.0361	1.0368	1.0375	1.0382	1.0388	225
230	1.0237	1.0249	1.0262	1.0272	1.0281	1.0291	1.0300	1.0308	1.0315	1.0323	1.0330	1.0336	230
235	1.0185	1.0198	1.0210	1.0221	1.0230	1.0239	1.0248	1.0257	1.0264	1.0271	1.0278	1.0284	235
240	1.0133	1.0145	1.0158	1.0168	1.0177	1.0187	1.0196	1.0204	1.0211	1.0218	1.0226	1.0232	240
245	1.0080	1.0093	1.0105	1.0115	1.0125	1.0134	1.0143	1.0151	1.0159	1.0166	1.0173	1.0179	245
250	1.0028	1.0040	1.0053	1.0063	1.0072	1.0081	1.0091	1.0099	1.0166	1.0113	1.0121	1.0127	250
255	0.9976	0.9989	1.0001	1.0011	1.0021	1.0030	1.0039	1.0047	1.0055	1.0062	1.0069	1.0075	255
260	0.9924	0.9936	0.9948	0.9959	0.9968	0.9977	0.9987	0.9995	1.0002	1.0009	1.0016	1.0023	260
265	0.9871	0.9884	0.9896	0.9906	0.9915	0.9925	0.9934	0.9942	0.9950	0.9957	0.9964	0.9970	265
270	0.9819	0.9831	0.9843	0.9854	0.9863	0.9872	0.9881	0.9890	0.9897	0.9904	0.9911	0.9918	270
275	0.9766	0.9778	0.9791	0.9801	0.9810	0.9820	0.9829	0.9837	0.9844	0.9852	0.9859	0.9865	275
280	0.9714	0.9726	0.9738	0.9749	0.9758	0.9767	0.9776	0.9785	0.9792	0.9799	0.9806	0.9812	280
285	0.9660	0.9672	0.9685	0.9695	0.9704	0.9714	0.9723	0.9731	0.9738	0.9745	0.9753	0.9759	285
290	0.9607	0.9620	0.9632	0.0642	0.9652	0.9661	0.9670	0.9678	0.9686	0.9693	0.9700	0.9706	290
295	0.9555	0.9567	0.9580	0.9590	0.9599	0.9608	0.9618	0.9626	0.9633	0.9640	0.9648	0.9654	295
300	0.9501	0.9514	0.9526	0.9536	0.9546	0.9555	0.9564	0.9572	0.9580	0.9587	0.9594	0.9600	300

Boiling and Melting Points of Organic Bodies[1]

	Melting point, C.°	Boiling point, C.°		Melting point, C.°	Boiling point, C.°
Acetone	....	57.1	Camphor	177.7	205.0
Acid:			Chloroform	− 63.2	61.2
Acetic	16.71	118.1	Cyanogen	− 34.4	− 20.7
Benzoic	121.0	249.1	Ethane	−177.5	− 93.0
Butyric	− 3.12	162.0 (about)	Ether	−117.6	34.6
Carbonic	− 78.2	− 57.0	Ethylene	−169.0	−102.5
Formic	8.51	100.6	Ethylene dibromide	....	160.0
Stearic	68.4	....	Glycerin	− 20.0	291.0
Succinic	185.0	....	Methane	−184.11	−164.7
Alcohol:			Naphthalene	80.1	217.72
Amyl	....	132.0	Nitrobenzene	5.17	208.3
Ethyl	−130.0 (about)	78.2	Phenol	41.1	181.4
Methyl	....	64.7	Carbon disulphide	....	46.3
Aldehyde	....	20.8	Carbon tetrachloride	22.0	76.7
Aniline	− 6.0	183.7	Toluene	− 98.0	110.0
Benzene	5.4	80.0			

[1] For the melting points of the elements, see p. 240. For melting points of inorganic compounds, see p. 210 *et seq.* This table was taken from the "Annuaire pour 1914, Bureau des Longitudes."

The Thermal Properties of Steam

Probably the most critical investigation yet made of the thermal properties of steam was that of G. A. Goodenough of the University of Illinois, from whose work the following formulas are taken:

The relation found between the pressure and temperature of the steam is as follows:

$$\log p = 10.5688080 - \frac{4876.643}{T} - 0.0155 \log T$$
$$- 0.00406258T + 0.00000400555T^2$$
$$- 0.00002 \left\{ 10 - 10 \left(\frac{t - 370}{100} \right)^2 + \left[\frac{t - 370}{100} \right] \right\}$$

where p is the pressure in pounds per square inch, and T the absolute temperature in Fahrenheit units, while t is the temperature in Fahrenheit degrees. The absolute zero is taken as − 459.6°F. For the specific volume of the steam Professor Goodenough gives the expression:

$$v - 0.017 = 0.59465\frac{T}{p} - (1 + 0.05129p^{1/2})\frac{C_1}{T^4}$$

where v denotes the volume in cubic feet per pound, and $\log C_1 = 10.82500$. The "heat content" of steam at different temperatures and pressures is:

$$i = 0.320T + 0.000063T^2 - \frac{23583}{T}$$
$$- \frac{C_3 p(1 + 0.0342p^{1/2})}{T^4} + 0.00333p + 948.7$$

where

$$\log C_3 = 10.79155$$

The entropy of superheated steam is given by the relation:

$$s = 0.73683 \log T + 0.000126T - \frac{11.7915}{T^2} - 0.25355 \log p - \frac{C_4 p(1 + 0.0342p)}{T^5} - 0.08085$$

where

$$\log C_4 = 10.69464$$

The thermal properties of steam at very high pressures and temperatures are stated to be as follows:

Temperature, degrees F.	Pressure, lb. per sq. in.	Volume of 1 lb., cu. ft.	Weight of 1 cu. ft., lb.	Heat content of Liquid, B.t.u.	Heat content of Vapor, B.t.u.	Latent heat, B.t.u.
600.0	1540.4	0.272	3.68	604.5	1164	560
620.0	1658.7	0.241	4.15	633.0	1151	518
640.0	2056.6	0.187	5.35	663.0	1136	473
660.0	2360.8	0.151	6.63	700.0	1112	412
680.0	2699.1	0.118	9.86	745.0	1080	335
700.0	3074.5	0.080	12.46	823.0	1016	193
706.3	3200.0	0.048	20.92	921.0	921	0

The following note and table, giving the constants of steam at ordinary temperatures, is from "Lubricants," 1914, p. 10.

The temperature of steam in contact with water depends upon the pressure under which it is generated. At ordinary atmospheric pressure (14.7 lb. per square inch) the temperature is 212°F., but as the pressure increases the temperature of both the steam and the water also increases.

Saturated steam is steam of the temperature due to its pressure, while superheated steam is steam heated to a temperature above that due to its pressure. Saturated steam cannot be cooled except by lowering its pressure. Steam in contact with water cannot be heated above the temperature due to its pressure.

The latent heat or heat of vaporization is obtained by subtracting from the total heat at any given temperature the heat of the liquid. Since the "total heat" is greater as the pressure increases, it will take more heat and consequently more fuel, to make a pound of steam as the pressure increases.

TABLE OF PROPERTIES OF SATURATED STEAM[1]

Pressure in pounds per square inch	Temperature, Fahrenheit	Total heat in heat units above 32°F. In the steam (H)	Total heat in heat units above 32°F. In the water (h)	Heat of vaporization of latent heat (L) in heat units $L=H-h$	Density or weight in pounds of 1 cu. ft.	Volume in cubic feet of 1 lb.	Factor of equivalent evaporation at 212°F.
1	101.99	1113.1	70.0	1043.0	0.00299	334.5	0.9661
2	126.27	1120.5	94.4	1026.1	0.00576	173.6	0.9738
3	141.62	1125.1	109.8	1015.3	0.00844	118.5	0.9786
4	153.09	1128.6	121.4	1007.2	0.01107	90.33	0.9822
5	162.34	1131.5	130.7	1000.8	0.01366	73.21	0.9852
6	170.14	1133.8	138.6	995.2	0.01622	61.65	0.9876
7	176.90	1135.9	145.4	990.5	0.01874	53.39	0.9897
8	182.92	1137.7	151.5	986.2	0.02125	47.06	0.9916
9	188.33	1139.4	156.9	982.5	0.02374	42.12	0.9934
10	193.25	1140.9	161.9	979.0	0.02621	38.15	0.9949
15	213.03	1146.9	181.8	965.1	0.03826	26.14	1.0003
20	227.95	1151.5	196.9	954.6	0.05023	19.91	1.0051
25	240.04	1155.1	209.1	946.0	0.06199	16.13	1.0099
30	250.27	1158.3	219.4	938.9	0.07360	13.59	1.0129
35	259.19	1161.0	228.4	932.6	0.08508	11.75	1.0157
40	267.13	1163.4	236.4	927.0	0.09644	10.37	1.0182
45	274.29	1165.6	243.6	922.0	0.1077	9.285	1.0205
50	280.85	1167.6	250.2	917.4	0.1188	8.418	1.0225
55	286.89	1169.4	256.3	913.1	0.1299	7.698	1.0245
60	292.51	1171.2	261.9	909.3	0.1409	7.097	1.0263
65	297.77	1172.7	267.2	905.5	0.1519	6.583	1.0280
70	302.71	1174.3	272.2	902.1	0.1628	6.143	1.0295
75	307.38	1175.7	276.9	898.8	0.1736	5.760	1.0309
80	311.80	1177.0	281.4	895.6	0.1843	5.426	1.0323
85	216.02	1178.3	285.8	892.5	0.1951	5.126	1.0337
90	320.04	1179.6	290.0	889.6	0.2058	4.859	1.0350
95	323.89	1180.7	294.0	886.7	0.2165	4.619	1.0362
100	327.58	1181.9	297.9	884.0	0.2271	4.403	1.0374
105	331.13	1182.9	301.6	881.3	0.2378	4.205	1.0385
110	334.56	1184.0	305.2	878.8	0.2484	4.026	1.0396
115	337.86	1185.0	308.7	876.3	0.2589	3.862	1.0406
120	341.05	1186.0	312.0	874.0	0.2695	3.711	1.0416
125	344.13	1186.9	315.2	871.7	0.2800	3.571	1.0426
130	347.12	1187.8	318.4	869.4	0.2904	3.444	1.0435
140	352.85	1189.5	324.4	865.1	0.3113	3.212	1.0453
150	358.26	1191.2	330.0	861.2	0.3321	3.011	1.0470
160	363.40	1192.8	335.4	857.4	0.3530	2.833	1.0486
170	368.29	1194.3	340.5	853.8	0.3737	2.676	1.0502
180	372.97	1195.7	345.4	850.3	0.3945	2.535	1.0517
190	377.44	1197.1	350.1	847.0	0.4153	2.408	1.0531
200	381.73	1198.4	354.6	843.8	0.4359	2.294	1.0545
225	391.79	1201.4	365.1	836.3	0.4876	2.051	1.0576
250	400.99	1204.2	374.7	829.5	0.5393	1.854	1.0605
275	409.50	1206.8	383.6	823.2	0.5913	1.691	1.0632
300	417.42	1209.3	391.9	817.4	0.644	1.553	1.0657
325	424.82	1211.5	399.6	811.9	0.696	1.437	1.0680
350	431.90	1213.7	406.9	806.8	0.748	1.337	1.0703
375	438.40	1215.7	414.2	801.5	0.800	1.250	1.0724
400	445.15	1217.7	421.4	796.3	0.853	1.172	1.0745
500	466.57	1224.2	444.3	779.9	1.065	0.939	1.0812

[1] KENT, "Mechanical Engineer's Pocket-Book," New York, 1913, p. 836.

Vapor Tensions of Various Metals[1]

(As calculated by J. W. Richards, "Metallurgical Calculations")

Vapor tension, mm. of mercury	Mercury at C.°	Lead at C.°	Silver at C.°	Gold at C.°	Cadmium at C.°	Zinc at C.°
0.0002	0	625	729	942	183	248
0.0005	10	658	766	987	200	267
0.0013	20	691	802	1031	216	286
0.0029	30	724	839	1075	233	305
0.0063	40	757	876	1120	250	324
0.013	50	790	913	1165	267	344
0.026	60	822	949	1209	283	363
0.050	70	855	986	1254	300	382
0.093	80	888	1023	1298	317	401
0.165	90	921	1059	1343	333	420
0.285	100	954	1096	1387	350	439
0.478	110	987	1133	1432	367	458
0.779	120	1020	1169	1476	383	477
1.24	130	1053	1206	1520	400	496
1.93	140	1086	1243	1565	417	516
2.93	150	1119	1280	1611	433	535
4.38	160	1151	1316	1654	450	554
6.41	170	1184	1353	1699	467	573
9.23	180[1]	1217[1]	1390[1]	1743[1]	483[1]	592[1]
14.84	190	1250	1427	1788	500	611
19.90	200	1283	1463	1832	517	630
26.25	210	1316	1500	1877	533	649
34.70	220	1349	1537	1921	550	668
45.35	230	1382	1574	1965	567	687
58.82	240	1415	1610	2010	584	706
75.75	250	1448	1647	2055	600	726
96.73	260	1480	1684	2099	617	745
123.0	270	1513	1720	2144	634	764
155.0	280	1546	1757	2188	650	783
195.0	290	1579	1794	2233	667	802
242.0	300	1612	1830	2277	684	821
300.0	310	1645	1867	2322	700	840
369.0	320	1678	1904	2366	717	859
451.0	330	1711	1941	2410	734	878
548.0	340	1744	1977	2455	750	897
663.0	350	1777	2014	2500	767	915
760.0	357[2]	1800[2]	2040[2]	2530[2]	780[2]	930[2]
Atmospheres pressure						
2.1	400	1951	2197	2722	851	1012
4.25	450	2116	2380	2945	934	1107
8.0	500	2280	2564	3167	1018	1203
13.8	550	2445	2747	3390	1101	1298
22.3	600	2609	2931	3612	1185	1394
34.0	650	2774	3114	3835	1268	1489
50.0	700	2938	3298	4057	1352	1585
72.0	750	3103	3481	4280	1435	1680
102.0	800	3267	3665	4502	1519	1776
137.5	850	3436	3848	4725	1602	1871
162.0	880	3525	3958	4858	1652	1928

[1] Approximate boiling points *in vacuo*.
[2] Approximate boiling points at normal pressures.

Mean Values of the Vapor Pressure of As_2O_3

Temperature	Vapor pressure	As_2O_3 per 1000 cu. ft. of gas	Temperature	Vapor pressure	As_2O_3 per 1000 cu. ft. of gas
°C.	Mm. of mercury	Pounds	°C.	Mm. of mercury	Pounds
100	0.000266	0.000386	220	2.065	3.00
120	0.00180	0.00261	240	5.96	8.71
140	0.01035	0.0150	260	15.7	23.2
160	0.0473	0.0685	280	38.5	58.6
180	0.186	0.270	300	89.1	144.0
200	0.653	0.947	....	....	....

This table, from "Tech. Paper 81," U. S. Bureau of Mines, may be used as a rough basis for the calculation of arsenic in smeltery gases. The vapor pressure of arsenic volatilized from flue dust at a given temperature is about half of the value in the table for that temperature. The heat of sublimation of arsenic varies from about 28,000 gram-cal. at 110°C. to about 25,000 at 290°C. per gram-molecule of arsenic (396 grams).

Cryohydrates. Salt and Ice Mixtures[1]

Name of salt	Cryohydric point, degrees C.	Percentage anhydrous salt in ice mixture
Calcium chloride............	−55.0	29.8
Sodium bromide.............	−24.0	41.33
Sodium chloride............	−22.0	23.60
Sodium nitrate..............	−17.5	40.80
Ammonium chloride.........	−15.0	19.27
Magnesium sulphate.........	− 5.0	21.86

[1] "General Electric Review" 1915.

Cooling Mixtures of Salt and Water[1]

	Mixed with 100 parts water	Temperature falls	
		From C.°	To C.°
Alum-crystallized................	14	10.8°	9.0
Ammonium carbonate...........	30	15.3	3.2
chloride............	30	13.3	− 5.1
nitrate.............	60	13.6	−13.6
sulphate............	75	13.2	6.8
sulphocyanate........	133	13.2	−18.0
Calcium chloride crystallized......	250	10.8	−12.4
Magnesium sulphate crystallized...	85	11.1	−3.1
Potassium chloride...............	30	13.2	−3.0
iodide...............	140	10.8	−11.7
nitrate..............	16	13.2	− 3.0
sulphate.............	12	14.7	−11.7
sulphocyanate.........	150	10.8	−23.7
Sodium acetate, cryst............	85	10.7	− 4.7
carbonate, cryst..........	40	10.7	1.6
chloride.................	36	12.6	10.1
hyposulphite, cryst.......	110	10.7	− 8.0
nitrate........	75	13.2	− 5.3
phosphate, cryst..........	14	10.8	7.1
sulphate, cryst...........	20	12.5	5.7

[1] Cremer and Bicknell's "Chemical and Metallurgical Hand Book."

Capillary Constants for Molten Metals

(Given by Landolt, $r \times h = a^2$)[1]

Metal	S. W. Smith	Quincke	Siedentopf	Grunmach	
Selenium....	....	4.41	....	....	....
Antimony...	8.65	9.90	....	....	....
Bismuth.....	6.91 7.53	9.76	8.755	....	....
Lead........	8.36 8.12	9.98	9.778	9.060	....
Mercury.....	6.72 6.73	8.234	....	7.39 6.09	Stöckle 6.548
Tin.........	14.57 14.55 14.97	19.43	17.87	10.27	....
Cadmium....	....	19.8	21.25	....	....
Aluminum...	45.09	No values given			
Zinc........	25.05 24.54	28.6 30.6	....	....	....
Silver.......	18.57 18.47	15.94	....	....	Gradenwitz 14.5
Copper......	28.23 29.47	14.44	....	....	....
Gold........	11.29		....	....	Heydweiller 6.90
Iron.......	....	25.81 27.14	....	....	....

Comparison of Values for Surface Tensions of Metals Obtained by Various Workers

(Given by Landolt)[1]

Metal	S.W.Smith	Quincke	Siedentopf	Grunmach	
	Dynes per centimeter	Dynes per centimeter	Dynes per centimeter	Dynes per centimeter	Dynes per centimeter
Selenium....	....	92.5	....	....	....
Antimony...	274.0	317.2	....	....	....
Bismuth.....	346.0	464.9	429.5	....	....
Lead........	424.5	535.9 $457\frac{\text{mg.}}{\text{mm.}}$	509.5 $519\frac{\text{mg.}}{\text{mm.}}$	$482\frac{\text{mg.}}{\text{mm.}}$	....
Mercury.....	447.5	547.2	....	491.2 405.0	Stöckle 435.6
Tin.........	480.0	681.2 $598\frac{\text{mg.}}{\text{mm.}}$	612.4 $624\frac{\text{mg.}}{\text{mm.}}$	352 359	....
Aluminum...	520.0	No values recorded			....
Zinc........	707.5	967.4 1103.7	....	....	....
Cadmium....	....	815.0	832.0	....	....
Silver.......	858.0	782.4	....	....	Gradenwitz, 751.0
Gold........	1018.0	581.0	....	....	Heydweiller 612.2
Copper......	1178.0	....	....	....	....

[1] Sydney W. Smith, paper before the Institute of Metals, September, 1914.

The surface tensions of liquid metals are periodic functions of their atomic weights. In each period the surface tension decreases slightly, the metal of lowest atomic weight having the highest surface tension.

Heat Conductivity (K)

A plate of the given substance 1 cm. thick, with parallel sides having a difference in temperature of 1°C., conducts enough heat per square centimeter per second to heat *K* grams of water from 0° to 1°C. The table is one compiled from various sources. See also Hering's Thermal Resistivity Table on p. 146.

Metals	Temperature, degrees C.	*K*
Aluminum	18	0.504
Aluminum	100	0.492
Aluminum	−160	0.514
Antimony	0 to 30	0.044
Antimony	100	0.040
Bismuth	0	0.0177
Bismuth	100	0.0161
Bismuth	−186	0.025
Brass, red	0	0.2460
Brass, red	100	0.2847
Brass, yellow	0	0.2041
Brass, yellow	100	0.2540
Cadmium	0	0.02213
Cadmium	100	0.02045
Cadmium	−160	0.239
Copper	0	1.0405
Copper	100	0.908
Copper	−160	1.079
Copper (containing iron)	0 to 30	0.954
Copper (phosphor bronze)	0	0.7198
Copper (phosphor bronze)	100	0.7226
German silver	31	0.081
German silver	100	0.0887
Gold	18	0.700
Iron	−160	0.152
Iron, wrought (1 per cent. C.)	18	0.144
Iron, wrought	50	0.1772
Iron, wrought	100	0.1567
Iron, wrought	150	0.1447
Iron, wrought	200	0.1357
Iron, wrought	275	0.1240
Iron (pure)	18	0.161
Iron (Bessemer steel)	15	0.0964
Iron (puddled)	15	0.1375
Lead	18	0.083
Lead	100	0.076
Magnesium	0 to 100	0.376
Mercury	0	0.01479
Mercury	50	0.01893
Mercury	100	0.024
Nickel	0	0.14
Palladium	18	0.17
Platinum	10 to 97	0.19
Silver	10 to 97	1.096
Steel (1 per cent. C.)	18	0.115
Tin	0 to 30	0.151
Wood's metal (99.05 Bi + 0.95 Sn)	....	0.008
Wood's metal (93.86 Bi + 6.14 Sn)	....	0.012
Zinc	0 to 30	0.303

Non-metals	Temperature, degrees C.	K
....	0	5.7
ıt.....................................	below 0°	0.0001625
....	below 0°	0.000405
ı (compressed).....................	below 0°	0.00055
ı wool...............................	....	0.0004
....	....	0.00009
ɜl.....................................	below 0°	0.000355
(crown)..............................	10–15	0.00163
(flint)................................	10–15	0.00143
....	....	0.005
r of Paris..........................	....	0.0013
.n.....................................	0	0.0006
s sand...............................	18–98	0.00060
....	below 0°	0.00481
ıric acid............................	9–15	0.000765
....	0	0.001203
....	40.8	0.001555
(dry pine), dry walnut............	....	0.0004
na brick.............................	0°–700°	0.00204
os paper.............................	....	0.0006
oard..................................	....	0.0005
owdered............................	0°–100°	0.00044
....	....	0.00013
ick....................................	0°–1300°	0.00310
ick....................................	0°–500°	0.00140
ick dust.............................	20°–98°	0.00028
tort carbon, solid................	0°–100°	0.0177
ite....................................	....	0.012
ite-retort dust....................	20°–100°	0.00040
rial earth..........................	17°–98°	0.00013
rial earth..........................	0°–650°	0.00038
sia brick............................	0°–1300°	0.00620
sia-calcined Grecian granular......	20°–100°	0.00045
sia-calcined light porous...........	20°–100°	0.00016
site-brick dust.....................	20°–100°	0.00050
perpen. to cleavage).............	....	0.018
....	....	0.0003
r, Para...............................	....	0.00045
st.....................................	....	0.00012
ool....................................	....	0.00019

Table of Thermal Resistivities[1]

APPROXIMATELY IN ORDER OF RESISTIVITY

(Temperature in Centigrade degrees)

	Thermal ohms[1]		
	Inch cube	Centimeter cube	Reference
Silver, 0°–100°	0.094	0.24	LB
Copper (electrode mean), 100°–197°	0.090	0.23	H
Copper (electrode mean), 100°–837°	0.11	0.27	H
Copper, 0°–100°, about	0.11	0.27	LB
Copper	0.13	0.32	LB
Copper, cast	0.12	0.29	CJ
Copper, rolled	0.11	0.28	CJ
Copper, rolled	0.13	0.32	WF
Aluminum, 0°–100°	0.27	0.69	LB
Graphite, Acheson (electrode mean), 100°–390°	0.28	0.71	H
Graphite, Acheson (electrode mean), 100°–914°	0.32	0.82	H
Brass, 0°–100°	0.36	0.92	LB
Iron (electrode mean), 100°–398°	0.28	0.71	H
Iron (electrode mean), 100°–398°	0.43	1.1	H
Iron, wrought	0.22	0.55	CJ
Iron, wrought, 0°	0.46	1.2	LB
Iron, wrought, 275°	0.76	1.9	LB
Iron, wrought	0.79	2.0	WF
Iron, cast	0.26	0.66	CJ
Iron, cast, 30°	0.63	1.6	LB
Steel	0.24	0.60	CJ
Steel	0.81	2.1	WF
Steel, various	0.81	2.1	LB
Steel, 10 per cent. manganese	3.0	7.7	LB
Platinum	0.25	0.63	CJ
Platinum, 18°–100°	0.55	1.4	LB
Platinum	1.1	2.9	WF

[1] HERING uses an expression, the thermal ohm, which is the resistance through which 1 watt of heat flow will pass when the temperature drop is 1°C. Hence, if R is the thermal resistance in thermal ohms, W the flow of heat in watts and T the temperature in Centigrade degrees:

$$W = \frac{T}{R}$$

Or if r is the specific thermal resistance in thermal ohms per centimeter cube then

$$R = \frac{rL}{S}$$

where L is length and S is cross section.

To reduce a thermal conductivity in gram calories per second to resistivity in thermal ohms, multiply the reciprocal of the conductivity by 0.2388 when both are for 1 cm.[3] To reduce gram calories to watts, multiply by 4.186. In order to compare thermal resistivities MR. HERING called that of silver the unit, and reduced all values to this base.

To use the data of the table for all purposes it may be remembered that

watts × 0.00134111 = horse power
watts × 0.0568776 = B.t.u. per minute.

	Thermal ohms[1]		
	Inch cube	Centimeter cube	Reference
Carbon (electrode mean) 100°–942°	0.72	1.9	H
Carbon (electrode mean) 100°–360°	1.05	2.7	H
Lead	0.33	0.83	CJ
Lead	1.10	2.8	WP
Lead, 0°–100°	1.2	3.0	LB
Plumbago brick, about 1000°	3.8	9.6	WQ
Carborundum brick, about 1000°	4.1	10.3	WQ
Mercury, 0°–50°	5.5	14.1	LB
Quartz, 0°	5.9	15.0	LB
Graphite (probably plumbago) 7°	8.0	21.0	LB
Retort carbon, 0°	9.1	23.0	LB
Magnesia brick, about 1000°	13.0	34.0	WQ
Stone, calcareous, fine	16.0	42.0	P
Chromite brick, about 1000°	16.0	42.0	WQ
Ice	16.0	42.0	LB
Marble, fine grained, gray	9.8	25.0	P
Marble, coarse grained, white	12.0	31.0	P
Marble, 30°	19.0	48.0	LB
Stone, calcareous, ordinary	20.0	51.0	P
Firebrick, probably room temperature	21.0	53.0	D
Firebrick, about 1000°	22.0	57.0	WQ
Firebrick, mean for 500°–1300°	23.0	57.0	Z
Firebrick, mean for 0°–1300°	30.0	77.0	Z
Firebrick, about 400°–800°	44.0	112.0	CE
Firebrick, mean for 0°–500°	67.0	171.0	Z
Checker brick, about 1000°	24.0	61.0	WQ
Gas retort brick, about 1000°	25.0	63.0	WQ
Slate, 94°	26.0	67.0	LB
Building brick, about 1000°	29.0	72.0	WQ
Glass pot, about 1000°	35.0	89.0	WQ
Porcelain, 95°	38.0	96.0	LB
Terracotta, about 1000°	41.0	104.0	WQ
Chalk, solid	43.0	109.0	LB
Cement, Portland, neat, 35°	44.0	110.0	N
Cement, Portland, 90°	132.0	336.0	LB
Lava	47.0	120.0	LB
Silica brick, about 1000°	47.0	120 0	WQ
Kieselguhr brick, about 1000°	52.0	133.0	WQ
Red brick wall, average 8-in.–40-in. walls	62.0	160.0	W
Water, room temperature	72.0	180.0	LB
Glass, 28°	87.0	220.0	LB
Plumbago, 20°–155°, 26.1 per cent. solid matter	96.0	240.0	O
Fine sand, 20°–155°, 51.4 per cent. solid matter	109.0	276.0	O
Coarse sand, 20°–155°, 52.9 per cent. solid matter	110.0	280.0	O
Cork, solid	131.0	333.0	LB
Plaster of Paris, 0°	105.0	266.0	LB
Plaster of Paris, 20°–155°, 36.8 per cent. solid matter	221.0	562.0	O
Slag concrete, 1 slag: 0.61 cement by weight, 50°	178.0	453.0	N
Pumice stone, 18.2 lb. per cu. ft., 50°	169.0	430.0	N
Pumice stone	187.0	477.0	LB
Brick dust, sifted	204.0	518.0	P
Asbestos, 20°–155°, 34.2 per cent. solid matter	139.0	353.0	O
Asbestos, 36 lb. per cu. ft., 600°	166.0	422.0	N
Asbestos, 36 lb. per cu. ft., 50°	221.0	562.0	N
Asbestos with air cells	416.0	1016.0	S
Cardboard, below 0°	239.0	606.0	LB

	Thermal ohms.[1]		
	Inch cube	Centimeter cube	Reference
Ebonite, 48°	251	637	LB
Petroleum, 13°	265	672	LB
Wood pine, parallel to fiber	313	796	LB
Many liquids (hydrocarbons, etc.)	313	796	LB
Anthracite	317	803	LB
Chalk, 20°–155°, 25.3 per cent. solid matter	332	844	O
Very porous slag, 22.5 lb. per cu. ft., 50°	356	905	N
Zinc white, 20°–155°, 8.8 per cent. solid matter	398	1010	O
Infusorial earth, 21°–175°	415	1050	B
Infusorial earth 20°–155°, 11.2 per cent. solids.	435	1110	O
Infusorial earth, 20°–155°, 6 per cent. solid matter	472	1200	O
Infusorial, earth, burned, 12.5 lb. per cu. ft., 450°	263	1675	N
Infusorial earth, burned, 12.5 lb. per cu. ft., 50°.	477	1220	N
Infusorial earth, loose, 21.8 lb. per cu. ft., 350°.	427	1090	N
Infusorial earth, loose, 21.8 lb. per cu. ft., 50°.	562	1430	N
Infusorial earth	745	1890	C
Magnesia carb., 85 per cent., 20°–188°	537	1370	S
Magnesia, calcined, 20°–155°, 28.5 per cent. solids	160	470	O
Magnesia, calcined, 20°–155°, 4.9 per cent. solids	544	1380	O
Magnesia calcined, 20°–155°, 2.3 per cent. solids	554	1410	O
Magnesia, calcined, 21°–175°	572	1450	B
Charcoal, pine, 20°–155°, 11.9 per cent. solid matter	494	1260	O
Charcoal, from leaves ,11.9 lb. per cu. ft., 100°	537	1370	W
Charcoal, from leaves, 11.9 lb. per cu. ft., 50°.	603	1530	N
Charcoal	723	1840	C
Feathers, 20°–155°, 2 per cent. solid matter	577	1470	O
Sawdust, 13.4 lb. per cu. ft., 50°	614	1560	N
Sawdust	620	1570	C
Sawdust, 13.4 lb. per cu. ft., 50°	765	1950	LB
Cork, granulated and compressed, 20°–188°	467	1190	S
Cork, ground, 10 lb. per cu. ft., 200°	614	1560	N
Cork, ground, 10 lb. per cu. ft., 50°	797	2030	N
Air, 20°–155°	143	364	O
Air, 0°	1700	4320	LB
Cotton wool, 20°–155°, 1 per cent. solid matter.	596	1520	O
Cotton wool, 20°–155°, 2 per cent. solid matter.	659	1570	O
Cotton wool, 5.05 lb. per cu. ft., 100°	572	1460	N
Cotton wool, 5.05 lb. per cu. ft., 50°	627	1600	N
Cotton wool	830	2110	C
Cotton wool, loose	2170	5500	LB
Cotton wool, compressed	2810	7120	LB
Hair felt, 20°–155°, 9.2 per cent. solid matter	633	1610	O
Hair felt, 21°–175°	790	2010	B
Hair felt	865	2200	C
Hair felt, below 0°	1080	2740	LB
Lampblack, 20°–155°, 5.6 per cent. solid matter	697	1770	O
Fine quartz sand	718	1820	LB
Silk, 6.3 lb. per cu. ft., 100°	662	1690	N
Silk, 6.3 lb. per cu. ft., 50°	752	1920	N
Wool, sheep's, 20°–155°, 2.1 per cent. solid matter	616	1570	O

	Thermal ohms[1]		
	Inch cube	Centimeter cube	Reference
Wool, sheep's, 8.5 lb. per cu. ft., 50°	676	1720	N
Wool, sheep's, 8.5 lb. per cu. ft., 100°	745	1890	C
Wool, sheep's,	803	2050	N
Mineral wool, 21°–175°	737	1870	B
Mineral wool, 0°–18°	1010	2570	C
Hard rubber	1060	2680	LB
Wood, pine, radially	1070	2720	LB
Loose fibrous materials, 9°	1540	3920	LB
Flannel	2650	6720	LB

B—George M. Brill. *Trans.*, Am. Soc. Mech. Eng., XVI, p. 827. Coverings on 8-in. steam pipes.

C—J. J. Coleman. *Engineering*, Sept. 5, 1884, p. 237. Ice melted in cube surrounded with the materials. Temperatures 0–18° and 0–38° C. The values were given relatively to each other; to reduce them to absolute measure it is here assumed that the value for sawdust is 620, thermal ohm, inch cube units.

CE—Clement and Egy.

CJ—Calvert and Johnson. Relative values based on silver. Reduced here on the basis that the conductivity of silver is 1.0 in gram calories per second, centigrade, centimeter cube units.

D—Depretz, Hood. "Warming and Ventilating Buildings," p. 249. Given relatively to marble, here assumed to be 10 thermal ohms, inch cube units.

H—Carl Hering. "The Proportions of Electrodes for Furnaces." (Table.) Paper read before the Am. Inst. Elec. Eng., March 31, 1910. Mean values when materials are used as furnace electrodes.

LB—Landolt and Boernstein tables. The values here chosen are mostly approximate means of the generally numerous and sometimes greatly differing values given by different observers. For the individual values and for the authorities see those tables. They also include values for very many other materials.

N—Wilhelm Nussel. *Zeit. Ver. Deut. Eng.*, June, 1908, p. 906, table, p. 1006. Materials were placed between two concentric metallic spheres or cubes. Heat generated electrically in interior. Temperature measured with thermocouples at numerous depths in the material after several days' heating. As here given they represent the resistivities at the temperatures stated, not the means over a range. Probably the best and most reliable determinations published. His conductivities are here assumed to be in terms of kilogram calories per hour, centigrade, meter cube, units; although not so stated directly in the original, it is undoubtedly what is meant. An abstract appeared in the *Eng. Digest*, August, 1908, p. 168, in which the units are reduced to thermal units, feet, inches and Fahrenheit degrees; the formula there given omits to say that it is necessary to multiply by the temperature also.

O—Prof. Ordway. *Trans.*, Am. Soc. Mech. Eng., Vol. VI, 1884–5, p. 168. Tested in plates 1 in. thick between two flat iron surfaces, one of them heated by steam, the heat emitted by the other being measured calorimetrically. Extended, carefully made researches; presumably very good values. There is an error in the heading in Table VII; square inch should read square meter, as in the others.

P—Peclet, Box. "Practical Treatise on Heat." Presumably ordinary weather temperatures.

S—H. G. Stott. *Power*, 1902. Pipe coverings. 200 ft. of 2-in. pipe heated electrically to constant temperature. Coverings were somewhat over 1 in. thick; they are here reduced to 1 in. Heat transmitted to air, hence these resistances include that at the surface.

W—Wolff. *Jour. Frank. Inst.*, 1893. The transmission of heat from the interior to the exterior of buildings through the walls; hence ordinary weather temperatures. Prescribed by law by German Government for heat-

ing plants. Said to agree well with good American practice. The value here given is an average of all the individual ones, omitting the first one, which differed greatly from all the others.

WF—WIEDEMANN and FRANZ; relative values based on silver. Reduced here on the basis that the conductivity of silver is 1.0 in gram calories per second, centigrade, centimeter cube, units.

WQ—WOLOGDINE, QUENEAU. The temperatures were about 1000°C.; the materials were those of commerce and do not refer to extra pure or to inferior grades. The present writer is of the opinion, based on the method used in the tests, that these values are probably too low.

Z—Source lost, but probably fairly good values.

For further information the reader is referred to *Metallurgical and Chemical Engineering*, September, 1909, p. 383; February, 1909, p. 72; December, 1911, p. 652.

According to WILLIAM NUSSEL, thermal conductivity increases by 1/273 for each degree Centigrade rise in temperature.

THERMAL CONDUCTIVITY OF REFRACTORIES[1]

Woodland firebrick		Quartzite (ganister and clay)	Star silica (ganister and lime)	Magnesite (dead burned)
SiO_2	52.93	73.91	95.85	2.50
Al_2O_3	42.69	22.87	0.88	0.50
Fe_2O_3	1.98	1.48	0.79	7.00
CaO	0.33	0.29	1.80	2.75
MgO	0.38	0.31	0.14	86.50
Alkalis	1.55	1.20	0.39	....
Loss on ignition	....	....	....	0.10
Density	1.91	1.91	1.56	2.46
K at 100°C.	0.0043	0.0051	0.0056	0.0343[1]
K at 1000°C.	0.0086	0.0086	0.0108	

Flow of Heat Inward from a Heated Plane Face[3]

Starting with the simple fundamental law for the flow of heat in the steady state—namely, that the amount of heat conducted varies directly as the conductivity, area, time and temperature difference, and inversely as the thickness—it is not particularly difficult to derive the solution for this case with the aid of Fourier's Series. For such derivation, however, the reader is referred to any treatise on heat conduction where he will find it given in the form:

$$T = T_0 \frac{2}{\sqrt{\pi}} \int_{\frac{x}{2h\sqrt{t}}}^{\infty} e^{-\beta} d\beta$$

This means that for a body initially at the zero of our temperature scale, whose plane surface is suddenly heated to and maintained at T_0, the temperature T at a distance x from this surface will be given t seconds later by this integral. As to the meaning of h, a little thought will serve to show that inasmuch as the temperature of the substance must be raised by the heat

[1] From a paper by BOYD DUDLEY, JR., read at the Atlantic City meeting of the American Electrochemical Society, April, 1915.

[2] From 445° to 830°C. K is expressed in gram calories per second per inch cube per degree Centigrade, a peculiar unit.

[3] Taken from an article by L. R. INGERSOLL in *Eng. News*, Oct. 30, 1913.

wave as it travels into the body, the rate of this penetration will depend not only on the conductivity, but on the specific heat and density of the material as well. This is taken account of in the constant h which is defined by the relation

$$h^2 = \frac{k}{c\rho}$$

k, c and ρ being respectively the conductivity, specific heat and density of the material. The quantities x, h and t being known, T can be determined. Tables I and II give the values of this integral, and of the constant h^2, or *thermal diffusivity.*

TABLE I.—VALUES OF INTEGRAL $E = \frac{2}{\sqrt{\pi}} \int_{\frac{x}{2h\sqrt{t}}}^{\infty} e^{-\beta^2} d\beta$

$x/2h\sqrt{t}$	E	$x/2h\sqrt{t}$	E	$x/2h\sqrt{t}$	E
0.00	1.000	0.45	0.525	1.40	0.048
0.02	0.987	0.50	0.480	1.50	0.034
0.04	0.955	0.55	0.437	1.60	0.024
0.06	0.932	0.60	0.396	1.70	0.016
0.08	0.910	0.65	0.358	1.80	0.0109
0.10	0.888	0.70	0.322	1.90	0.0072
0.12	0.865	0.75	0.288	2.00	0.0047
0.14	0.843	0.80	0.258	2.10	0.0030
0.16	0.821	0.85	0.229	2.20	0.0019
0.18	0.800	0.90	0.203	2.30	0.0011
0.20	0.777	0.95	0.179	2.40	0.0007
0.25	0.724	1.00	0.157	2.50	0.0004
0.30	0.671	1.10	0.120	2.60	0.0002
0.35	0.621	1.20	0.090	2.70	0.0001
0.40	0.572	1.30	0.066	∞	0.0000

Examples.—The use of these tables is best shown by solving some specific examples:

1. A massive granite block at 20°C. (68°F.) has one face (rapidly) heated to 200°C. (392°F.). What will be the temperature at a depth of 10 cm. (4 in.) after 1 hour?

Since the theory is based on the assumption of an initial temperature of zero the temperature scale must be shifted in this case by subtracting 20°, which will be added again later. Taking h^2 from Table II as 0.0155, t as 3600 (seconds) and x as 10 (cm.), the quantity $x/2h\sqrt{t}$ becomes 0.67. This gives, from Table I, $E = 0.34$; hence the rise in temperature would be $T = 180E$, or 61°, making a final temperature of 81°C. (178°F.).

2. The surface of a dry soil initially throughout at 6°C. (43°F.) is cooled to −20°C. (−4°F.). How long before water-pipes at a depth of 152 cm. (5 ft.) will be in danger of freezing?

Here we have, after shifting the temperature scale,

$$-6 = -26E, \text{ or } E = 0.23$$

From Table I, then, $x/2h\sqrt{t} = 0.85$, which, with $h^2 = 0.0031$, gives $t = 2{,}600{,}000$ seconds or 30 days.

TABLE II.—VALUES OF THERMAL CONDUCTIVITY CONSTANTS IN C. G. S.[1] UNITS[2]

Material	Temperature, deg. C.	Conductivity, k	Diffusivity, h^2
Air	0	0.000055	0.179
Aluminum	18	0.480	0.826
Brass (yellow)	0	0.204	0.339
Brick (firebrick)	0–800	0.0040	0.0074
Brick (in masonry)	....	0.0020	0.0050
Concrete (cinder)	....	0.00081	0.0031
Concrete (stone)	....	0.0022	0.0058
Copper	18	0.918	1.133
Cork (ground)	....	0.00012	0.0017
Glass (ordinary)	....	0.0024	0.0057
Granite	....	0.0081	0.0155
Ice	....	0.0052	0.0112
Iron (wrought or mild steel)	....	0.1436	0.173
Iron (cast, also high-carbon steel)	....	0.108	0.121
Lead	18	0.0827	0.237
Limestone	....	0.0050	0.0092
Magnesium carbonate (85 per cent. steam-pipe covering)	....	0.00017	....
Marble (white)	....	0.0050	0.0090
Nickel	18	0.142	0.152
Rock material, average	....	0.0042	0.0118
Sandstone	....	0.0050	0.0133
Silver	18	1.006	1.737
Snow (fresh)	....	0.0003	0.0033
Soil (average, damp)	....	0.0037	0.0055
Soil (very dry)	....	0.00088	0.0031
Water	....	0.00143	0.00143
Wood (dry pine—across grain)	....	0.00009	0.00068
Wood (dry pine—with grain)	....	0.00030	0.0023

Flow of Heat Inward from Two Heated Faces

If a plate or slab of thickness l and initial temperature zero have both its faces suddenly heated to and kept at T_o, the temperature T in the middle plane, which will obviously be the last part of the body to heat up, may be obtained from the equation

$$T = T_o\left(1 - \frac{4}{\pi} 10^{-0.434\frac{h^2\pi^2 t}{l^2}} + \frac{4}{3\pi} 10^{-0.434\frac{9h^2\pi^2 t}{l^2}} - \ . \ . \ .\right)$$

t being the time in seconds and h^2 the thermal diffusivity. To

[1] The use of this system is almost compulsory in cases where thermal diffusivity is involved, since it is the only one in common use which is consistent in its choice of fundamental units. Thus the steam engineer's conductivity unit of the B.t.u. per hour, per square foot, per degree F., per inch in thickness, is not available in this case since it involves two different units of length, *i.e.*, the inch and foot. Similar objections may be raised against most of the other units in common use with the exception of the C. G. S.

Most of the values for metals are those of JÄGER and DIESSELHORST, Abh. d. phys-tech. Reichsanstalt, Vol. 3, p. 269 (1900). The others have been compiled from various sources. When not otherwise specified, ordinary temperatures are assumed.

[2] This table is also taken from INGERSOLL's article. Some of these constants differ from those given in the table on p. 144, but the differences are not serious, and since his diffusivity constants have been computed on this basis, it seems better to let the table stand as originally printed.

simplify computation, the values of this series have been tabulated as in Table III.

TABLE III.—VALUES OF THE FUNCTION

$$y = 1 - \frac{4}{\pi}\left(10^{-x} - \frac{1}{3}10^{-9x} + \frac{1}{5}10^{-25x} - \ . \ . \ . \ . \right) \text{where } x = 0.434\frac{h^2\pi^2 t}{l^2}$$

x	y	x	y	x	y
0.01	0.0000	0.11	0.0546	0.36	0.4444
0.02	0.0000	0.12	0.0692	0.38	0.4693
0.03	0.0000	0.13	0.0848	0.40	0.4931
0.035	0.0001	0.14	0.1009	0.45	0.5482
0.04	0.0005	0.15	0.1176	0.50	0.5974
0.045	0.0010	0.16	0.1345	0.60	0.6802
0.05	0.0021	0.17	0.1517	0.70	0.7460
0.055	0.0037	0.18	0.1690	0.80	0.7982
0.06	0.0055	0.19	0.1862	0.90	0.8397
0.065	0.0081	0.20	0.2033	1.00	0.8727
0.07	0.0113	0.22	0.2372	1.25	0.9284
0.075	0.0150	0.24	0.2702	1.50	0.9597
0.08	0.0194	0.26	0.3022	1.75	0.9774
0.085	0.0241	1.28	0.3331	2.00	0.9873
0.09	9.0294	0.30	0.3727	2.50	0.9960
0.095	0.0351	0.32	0.3912	3.00	0.9987
0.10	0.0412	0.34	0.4184	3.50	0.9996
....	....	....	....	4.00	0.9999

Examples.—A dry spruce cross-tie 11.4 × 17.8 cm. (4½ × 7 in.) in section and 71 cm. (28 in.) long, and at an initial temperature of 15°C. (59°F.), is placed in an oven which heats its surface to 137°C. (278°F.) for 10½ hours. What should be the temperature at the end of this period for a point near the center of the tie?

As the heat penetration will be largely due to conduction across the smallest dimension of the tie we shall neglect the other faces altogether. We have then, effectively, a plate of thickness 11.4 cm. and diffusivity 0.0068 (pine wood in Table II), which gives $x = 0.85$. Then from Table III, $y = 0.82$, making a rise in temperature of 0.82 (137° − 15°), or 100°. This gives a final temperature of 115°C. (239°F.). In an actual experiment this was found to be 113°C., checking our theory much more closely than could be expected, considering the approximations we have made in neglecting the other faces.

In the same way we can readily show by a few minutes' work with a slide-rule that the center of a plate of steel 2.54 cm. (1 in.) thick, which is plunged into molten lead, should rise to within 2 per cent. of the temperature of its faces in less than half a minute; the center of a firebrick 6.3 cm. (2½ in.) thick, heated by flue gases in a regenerator, should show more than half its surface change in temperature in 10 minutes, and more than three-quarters in 20 minutes; a disk of glass 20.3 cm. (8 in.) thick, which has been subjected to a recent heating or cooling of a dozen degrees should be kept with faces at constant tem-

perature for upwards of 10 hours to insure that the interio temperature is uniform to a small fraction of a degree.

Relative Conductivities of Metals for Heat and Electricity

The following table, compiled from various sources, i intended to show merely the general correspondence betwee: conductivity for heat and for electricity. For ordinary work the table of heat conductivities just preceding, and of electri resistivity just following, should be used. The electric conduc tivities are the reciprocals of the resistivities given in the late tables.

Metal (*in vacuo*)	Heat	Electricity	Metal (*in vacuo*)	Heat	Electricity
Silver	100	100	Iron	11.9	14.44
Copper	74	77.43	Steel	10.3	....
Gold	54.8	55.19	Platinum	9.4	10.53
Aluminum	31.33	....	Lead	7.9	7.77
Zinc	28.1	27.39	German silver	6.3	6.0
Brass	24	22.0	Antimony	4.03	....
Cadmium	20.06	....	Bismuth	1.8	1.8
Tin	15.4	11.45	Mercury	1.3	......

Relation of Heat and Electric Conductivity[1]

Material	Thermal conductivity / Electrical conductivity at 18°C.	Temperatur coefficient (this ratio, per cent.
Copper, commercial	6.76×10^{10}	....
Copper (1), pure	6.65×10^{10}	0.39
Copper (2), pure	6.71×10^{10}	0.39
Silver, pure	6.86×10^{10}	0.37
Gold (1), pure	7.27×10^{10}	0.36
Gold (2), pure	7.09×10^{10}	0.37
Nickel	6.99×10^{10}	0.39
Zinc (1)	7.05×10^{10}	0.38
Zinc (2), pure	6.72×10^{10}	0.38
Cadmium, pure	7.06×10^{10}	0.37
Lead, pure	7.15×10^{10}	0.40
Tin, pure	7.35×10^{10}	0.34
Aluminum	6.36×10^{10}	0.43
Platinum (1)	7.76×10^{10}	....
Platinum (2), pure	7.53×10^{10}	0.46
Palladium	7.54×10^{10}	0.46
Iron (1)	8.02×10^{10}	0.43
Iron (2)	8.03×10^{10}	0.44
Steel	9.03×10^{10}	0.35
Bismuth	9.64×10^{10}	0.15
Constantan (60 Cu, 40 Ni)	11.06×10^{10}	0.23
Manganin (84 Cu, 4 Ni, 12 Mn)	9.14×10^{10}	0.27

[1] Table used by SIR J. J. THOMSON at a lecture before the Institute (Metals, May, 1915. Attributed by him to JÄGER and DIESSELHORST.

Resistivity of Metals

(Microhms per cm.[3])

	−160°	0°	18°	100°	Temp. coeff. at 0°
Aluminum	0.81	2.8	2.94	4.13	0.0040
Antimony	....	36.0	40.5	....	0.0041
Bismuth	....	55.55	119.0	160.3	0.0035
Cadmium (drawn)	2.72	7.0	7.54	9.82	0.0042[5]
Copper (drawn)	0.49	1.58	1.78	2.36	0.0039
Calcium	....	7.5	10.5	....	....
Cobalt	....	....	9.71	....	0.0033[5]
Gold	0.68	....	2.42	3.11	0.0037
Arsenic	....	33.3	....	....	....
Iridium	....	....	5.3	....	....
Iron	....	....	9–15	16.8	0.0062
Iron (wrought)	5.4	....	13.9	18.8	0.0058
Lead (drawn)	7.43	19.0	20.8	27.7	0.0039
Lithium	....	8.4	....	....	....
Magnesium	....	4.35	....	....	0.0038
Mercury	....	94.07	95.57	....	0.00072
Molybdenum	....	....	4.1[2]	....	0.0050[5]
Steel	....	....	19.9	25.6	....
Nickel	5.9	....	11.8	15.7	0.0062[5]
Osmium	....	....	9.5[3]	....	....
Palladium	....	....	10.7	13.8	0.0035[5]
Platinum	2.4[4]	9.0	11.0	14.0	0.0037[5]
Potassium	....	6.64	....	....	....
Rhodium	....	....	6.0	....	....
Silver	0.56	1.50	1.65	2.13	0.00377
Sodium	....	4.74	....	....	....
Strontium	....	....	25.0[3]	....	....
Tantalum	....	....	14.6	....	0.0033[5]
Tellurium	....	....	21.0[3]	....	0.0040
Thallium	....	17.6	....	....	....
Thorium	....	....	40.1	....	....
Tin (drawn)	3.5	10.0	11.3	15.3	0.0043
Tungsten	....	....	5.0[2]	....	0.0051[5]
Zinc	2.2	5.6	6.1	7.9	0.00365

[1] At −183°. [2] At 25°. [3] At 20°. [4] At −204°. [5] From 18° to 100°.

The values at low temperatures are mostly Lee's; those at 18°, Jaeger and Diesselhorst's; those at 0° from a table compiled by Watt's, "Laboratory Course in Electrochemistry," while those at 100° are from various sources.

Alloys[1]

	−160°	0°	18°	100°	Temp. coeff. at 0°
German silver[2]	......	26.6	....	27.6	0.0003
Nichrome	......	95.5	....	....	0.00044
Brass	4.1	....	6.6	....	0.0010
Constantan	......	....	49.0	49.1	−0.000050 to +0.000050
Manganin[3]	43.13	....	43.50	42.1	0.000002 to 0.000039[4]
Phosphor bronze	......	....	5–10	....	....
Woods alloy	......	....	31.25	....	....

[1] Temperature coefficients from "Standard Handbook."
[2] 62 per cent. Cu, 15 Ni, 22 Zn.
[3] 84 per cent. Cu, 4 Ni, 12 Mn.
[4] Most samples of manganin have a zero temperature coefficient from 30° to 40°C.

Resistivities at High Temperatures[1]

(Values in italics are merely exterpolated)

500°C. 932°F.	Microhms, cm. cb.
Silver, solid	5.0
Copper solid	5.1
Gold, solid	6.62
Aluminum, solid	10.0
Brass, 2-1, solid	12.5
Molybdenum, solid	16.5
Tungsten (a, b), solid	18.0
Platinum (b), solid	25.3
Cadmium, fused	34.12
Platinum (a), solid	34.4
Tantalum, solid	36.0
Zinc, fused	36.60
Iron (a), solid, about	52.0
Tin, fused	54.62
Lead-tin alloy, fused	81.0
Ferronickel, solid	94.0
Lead, fused	102.85
Calido, solid	109.0
Krupp metal, solid	115.0
Nichrome II, solid	119.0
Bismuth, fused	139.9
Antimony, solid	152.0
	Ohms
Graphite (b)	0.00080
Graphite (a)	0.00084
Carbon (a)	0.0027
Carbon (d)	0.0028
Carbon (c)	0.0033
Carbon (b)	0.0037
Carbon powder	0.22
Silicon	0.094 to 0.23
Lead chloride, fused, 520°	0.418
Silver chloride, fused	0.547
Lead chloride, solid	0.824
Silfrax B	0.92
Copper chloride, fused	2.50
Graphite grains	2.70
Carbon grains (b), about	4.8
Carbon grains (a), about	8.5
Kryptol	10.0
Refrax	19.7
Boron, about	60.0
Silicon powder	120.0
Glass, about	330.0
Iron oxide, Fe_2O_3, powder	1260.0
Copper oxide, Cu_2O, powder	1570.0
Manganese oxide, MnO_2, powder	2200.0
Copper oxide, CuO	5640.0

1000°C. 1832°F.	Microhms cm. cb.
Copper, solid	9.42
Gold, solid	12.54
Silver, fused	17.01
Aluminum, fused	24.0
Molybdenum, solid	28.5
Tungsten (a), solid	30.5
Tungsten (b), solid	33.4
Platinum (b), solid	40.8
Brass, 2-1, fused	41.0
Tantalum, solid	57.0
Platinum (a), solid	66.0
Tin, fused	68.0
Lead-tin alloy, fused	98.0
Ferronickel, solid	105.0
Iron (a), solid, about	111.0
Calido, solid	122.0
Lead, fused	125.0
Nichrome II	128.0
Antimony (b), fused	136.0
Bismuth, fused	167.5
	Ohms
Graphite (b)	0.0006
Graphite (a)	0.0008
Carbon (d)	0.0021
Carbon (a)	0.0024
Carbon (c)	0.0030
Carbon (b)	0.0034
Carbon powder	0.12
Silfrax B	0.84
Sodium chloride, fused	0.90
Glass, roughly about	1.0
Graphite grains	1.7
Carbon grains (b)	1.9
Carbon grains (a)	2.8
Silicon powder	3.5
Refrax	3.7
Kryptol	4.8
Porcelain, about	15.0
Manganese oxide powder	15.7
Copper oxide, CuO, powder	18.0
Zinc oxide powder	26.7
Iron oxide, Fe_2O_3, powder	31.4
Quartz	110.0
Magnesium oxide powder	1400.0
Alundum	8000.0

[1] A table compiled by Carl Hering, "Metallurgical and Chemical Engineering," January, 1915.

1500°C. 2732°F.	Microhms, cm. cb.	1500°C. 2732°F.	Microhms, cm. cb.
Silver, fused	23.0		
Copper, fused	24.8	Iron (b), fused	166.0
Aluminum, fused	29.0		Ohms
Gold, fused	37.0	Graphite (b)	0.00058
Molybdenum, solid	40.5	Graphite (a)	0.00089
Tungsten, solid	43.0	Carbon (d)	0.0016
Tungsten (b), solid	50.0	Carbon (a)	0.0022
Platinum (b), solid	52.6	Carbon (b)	0.0029
Tantalum, solid (b)	74.4	Nernst filament, about.	0.5
Tantalum, solid (a)	78.0	Refrax	0.5
Tin, fused	80.5	Silfrax B	0.7
Platinum (a), solid	98.0	Carbon grains (b)	0.85
Iron (a), solid, about	131.0	Graphite grains	1.2
Calido, solid	136.0	Kryptol	3.4
Lead, fused	148.0	Alundum, about	750.0

Notes.—The resistivity depends to some extent on the state of the metal. In general, cold drawing increases while annealing diminishes the resistance. Winding a wire into a coil apparently increases its resistance. For pure metals the resistance is roughly proportional to the absolute temperature and would apparently vanish at absolute 0°. For alloys the rule does not hold even approximately. For pure metals the BRINNELL hardness number is indirectly proportional to the electric conductivity.

In "*Engineering*," Apr. 3, 1914, appeared a table of the relative resistances of metals in the liquid and solid states at the melting point.

$$\text{Metal}\,\frac{\text{resistance of liquid}}{\text{resistance of solid}}\text{ at melting point.}$$

Sodium	1.35(*a*)	1.47(*d*)	....	....
Potassium	1.36(*a*)	1.54(*d*)	2.1(*c*)	2.12(*g*)
Tin	2.2 (*b*)	2.21(*e*)	....	1.97(*g*)
Cadmium	1.8 (*b*)	1.96(*e*)	....	....
Lead	1.9 (*b*)	1.95(*e*)	....	....
Thallium	....	2.00(*e*)	....	....
Zinc	2.0 (*b*)	....	....	....
Mercury	4.0 (*a*)	4.08(*f*)	....	1.5 (*h*)
Antimony	0.7 (*b*)	....	....	....
Bismuth	0.46(*b*)	0.45(*e*)	....	0.46(*g*)

(*a*) A. MATTHIESSEN.
(*b*) L. DE LA RIVÉ.
(*c*) W. SIEMENS.
(*d*) E. F. NORTHRUP.
(*e*) G. VINCENTINI and D. OMODEI.
(*f*) P. CAILLETET and E. BOUTY.
(*g*) G. VASSURA.
(*h*) L. GRUNMACH.

Electric Conductance of Ore-forming Materials[1]

Metal	Good conductor	Inferior or non-conductor
Silver	Argentite, pyrargyrite, proustite.	
Copper	Chalcocite, chalcopyrite, bornite.	Cuprite, azurite, malachite, tetrahedrite, chrysocolla.
Lead	Galena.	Cerussite, pyromorphite, crocoite, wulfenite, anglesite, bournonite.
Cobalt	Smaltite, linnæite, cobaltite.	
Nickel	Gersdorffite, niccolite, rammelsbergite.	
Tin	Cassiterite.	Stannite.
Zinc		Blende, calamine, smithsonite, stibnite.
Antimony		
Iron	Pyrite, pyrrhotite, magnetite.	Marcasite, hematite, siderite, limonite, menaccanite, blackband.

[1] Hofman, "General Metallurgy."

Volume Resistivity of Solid Dielectrics[1]

(Materials arranged in order of decreasing resistivity)

Material	Resistivity, ohms-cm.	Material	Resistivity, ohms-cm.
Special paraffin......over	5000×10^{15}	Black electrose	100×10^{12}
Ceresin......over	5000×10^{15}	Tetrachlornaphthalene	50×10^{12}
Fused quartz......over	5000×10^{15}	Mica (India ruby stained)	50×10^{12}
Hard rubber	1000×10^{15}	German glass	50×10^{12}
Clear mica	200×10^{15}	Paraffined mahogany	40×10^{12}
[2] Sulphur	100×10^{15}	Stabalite	30×10^{12}
[2] Amberite	50×10^{15}	Plate glass	20×10^{12}
[2] Rosin	50×10^{15}	Hallowax No. 1001	20×10^{12}
[2] Mica (India ruby slightly		Dielectrite	5×10^{12}
stained)	50×10^{15}	Gummon	3×10^{12}
G. E. No. 55 R	40×10^{15}	Tegit	2×10^{12}
Hallowax No. 5055 B	20×10^{15}	Opal glass	1×10^{12}
Mica (brown African clear)	20×10^{15}		
Bakelite L558	20×10^{15}	Paraffined poplar	500×10^{9}
[2] Electrose No. 8	20×10^{15}	Paraffined maple	300×10^{9}
Selenium (in dark)	20×10^{15}	Italian marble	100×10^{9}
[2] Parowax (paraffin)	10×10^{15}	Bakelite micarta	50×10^{9}
Glyptol	10×10^{15}	Black condensite	40×10^{9}
[2] Shellac	10×10^{15}	Yellow condensite	40×10^{9}
Kavalier glass	8×10^{15}	Vulcabeston	20×10^{9}
[2] Insulate No. 2	8×10^{15}	White celluloid	20×10^{9}
[2] Sealing wax	8×10^{15}	Hard fiber	20×10^{9}
[2] Yellow electrose	5×10^{15}	Black galalith	20×10^{9}
[2] Duranoid	3×10^{15}	Lavite	20×10^{9}
[2] Murdock No. 100	3×10^{15}	White galalith	10×10^{9}
[2] Yellow beeswax	2×10^{15}	Hermit	10×10^{9}
Khotinsky cement	2×10^{15}	Red fiber	5×10^{9}
Ebonite	2×10^{15}	Marble, pink Tennessee	5×10^{9}
Porcelain	2×10^{15}	Gutta percha	2×10^{9}
[2] G. E. No. 55A	1×10^{15}	Marble, blue Vermont	1×10^{9}
[2] Moulded mica	1×10^{15}		
		Ivory	200×10^{6}
Unglazed porcelain	300×10^{12}	Slate	100×10^{6}
Redmonite (157.4)	200×10^{12}	Bakelite No. 140	20×10^{6}

[1] From publications of U. S. Bureau of Standards.
[2] Apparent resistivity taken after the voltage had been applied for 15 minutes.

Dielectric Constants Compared with Air[1]

The inductivity, dielectric constant, or specific inductive capacity K of a material may be defined as the ratio of the capacity of a condenser with the material as dielectric to its capacity when the dielectric is dry air. That is, if two exactly similar condensers, except for the dielectrics, have one plate of each connected, the other plate earthed, then the distribution of charge on the two will be proportional to K.

Solids	K	Solids	K
Amber	3.0	Silica, fused	3.5–3.6
Beeswax	1.86	Spermaceti	2.2
Calcite	7.5–7.7	Sulphur	2.2–3.9
Ebonite	2.05–3.15	Vaseline	2.17
Fluorite	6.8		
Glass, crown	5–7	**Liquids**	**K**
Glass, heavy crown	7–9		
Glass, flint	6.8–10		
Gutta percha	3.6		
Gypsum	6.3	Alcohol, methyl	35.4 at 13.4°C.
Ice (– 2°)	93.9	Alcohol, ethyl	26.8 at 14.7°C.
India rubber	2.1–2.3	Alcohol, amyl	16.0 at 20°C.
Marble	8.3	Bromine	3.1
Mica	4–8	Carbon disulphide	2.62
Paper, dry	2–2.5	Carbon tetrachloride	2.25 at 18°C.
Paper, impregnated	2.8–3.8	Olive oil	3.1–3.2
Paraffin wax	1.7–2.3	Kerosene	4.6–4.8
Pitch	1.8	Petroleum crude	2.0–2.2
Porcelain	4.4–6.8	Water	26
Quartz	4.5		
Resin	1.77–2.6		
Rocksalt	5.6	Gases vary from 0.9995 for helium to 1.0023 for carbon disulphide vapor. Sulphur dioxide has a value of 1.00086 at 15°C. and 760 mm. pressure.	
Rubber, vulcanized	4–8		
Selenium	6.1		
Shellac	2.7–3.7		

Resistance of Electrolytes, Copper Refining[2]

Strength solution, per cent.	$CuSO_4$		$FeSO_4$		H_2SO_4	
	Ohms per cc.	Ohms per cu. in.	Ohms per cc.	Ohms per cu. in.	Ohms per cc.	Ohms per cu. in.
2.5	92	37	....	....	....	....
5.0	53	21	....	....	4.8	1.9
7.5	....	....	65	26	....	....
10.0	31	12	....	....	2.5	1.0
15.0	24	10	34	14	1.8	0.7
17.5	22	9	....	....	....	....
20.0	....	....	....	....	1.5	0.6
25.0	....	....	....	....	1.4	0.56
30.0	....	....	25	10	1.37	0.55

[1] Compiled from various authorities.
[2] J. W. Richards, "Metallurgical Calculations."

Resistivity of Electrolytes
(Kohlrausch and Holborn)

Grams substance in 100 g. of solution	Sp. gr.	Resistivity, ohms per cc.	Temperature coefficient for 1°C.	Gram equivalents per liter
	H_2SO_4 at 18°C.			
1.0	....	21.93	0.00112	0.204
2.5	1.0161	9.24	0.00115	0.519
5.0	1.0331	4.82	0.00121	1.065
10.0	1.0673	2.57	0.00128	2.182
15.0	1.1036	1.85	0.00136	3.384
20.0	1.1414	1.54	0.00145	4.667
30.0	1.2207	1.36	0.00162	7.487
40.0	1.3056	1.48	0.00178	10.68
50.0	1.3984	1.86	0.00193	14.30
60.0	1.5019	2.70	0.00213	18.42
70.0	1.6146	4.67	0.00256	23.11
80.0	1.7320	9.13	0.00349	28.33
85.0	1.7827	10.30	0.00365	30.98
90.0	1.8167	9.38	0.00320	33.43
95.0	1.8368	9.84	0.00279	35.68
97.0	1.8390	12.50	0.00286	36.47
99.4	1.8354	118.00	0.00400	37.22
	HCl at 10°C.			
5.0	1.0242	2.55	0.00159	1.408
10.0	1.0490	1.59	0.00157	2.884
15.0	1.0744	1.35	0.00156	4.431
20.0	1.1001	1.32	0.00155	6.050
25.0	1.1262	1.39	0.00154	7.741
30.0	1.1524	1.52	0.00153	9.506
35.0	1.1775	1.70	0.00152	11.33
40.0	1.2007	1.95	....	13.22
	KOH at 15°C.			
4.2	1.0382	6.85	0.00188	0.619
8.4	1.0777	3.69	0.00187	1.580
12.6	1.1177	2.67	0.00189	2.515
16.8	1.1588	2.20	0.00194	3.477
21.0	1.2088	1.97	0.00200	4.534
25.2	1.2439	1.86	0.00210	5.599
29.4	1.2908	1.85	0.00222	6.778
33.6	1.3332	1.92	0.00237	8.001
37.8	1.3803	2.10	0.00258	9.319
42.0	1.4298	2.39	0.00284	10.730
	KCN at 15°C.			
3.25	1.0154	19.10	0.00208	0.508
6.5	1.0316	9.80	0.00194	1.031

RESISTIVITY OF ELECTROLYTES. *Continued*

Grams substance in 100 g. of solution	Sp. gr.	Resistivity, ohms per cc.	Temperature coefficient for 1°C.	Gram equivalents per liter
	$AgNO_3$ at 18°C.			
5.0	1.0422	39.47	0.00219	0.307
10.0	1.0893	21.20	0.00218	0.642
15.0	1.1404	14.78	0.00216	1.009
20.0	1.1958	11.57	0.00213	1.410
25.0	1.2555	9.53	0.00211	1.851
30.0	1.3213	8.14	0.00210	2.338
35.0	1.3945	7.17	0.00208	2.879
40.0	1.4773	6.45	0.00206	3.485
45.0	1.5705	5.88	0.00205	4.168
50.0	1.6745	5.44	0.00206	4.940
55.0	1.7895	5.09	0.00207	5.800
60.0	1.9158	4.80	0.00210	6.780
	$CuSO_4$ at 18°C.			
2.5	1.0246	92.4	0.00214	0.322
5.0	1.0513	53.2	0.00217	0.661
10.0	1.1073	31.4	0.00219	1.393
15.0	1.1675	23.8	0.00232	2.202
17.5	1.2003	21.9	0.00237	2.642

RESISTIVITY OF ELECTROLYTES

Grams substance in 100 g. of solution	Potassium chloride. resistivity, ohms per cc.	Sodium chloride resistivity, ohms per cc.	Calcium chloride resistivity, ohms per cc.
5	14.49	14.88	16.48
10	7.429	8.257	8.764
15	4.950	6.090	6.645
20	3.735	5.109	5.903
25	....	4.684	5.615

Grams substance in 100 g. of solution	Cadmium chloride resistivity, ohms per cc.	Ammon. sulphate resistivity, ohms per cc.	Cadmium sulphate resistivity, ohms per cc.
5	....	18.11	68.5
10	41.49	9.901	....
20	....	5.677	....
30	37.59	4.363	....

RESISTIVITY OF ELECTROLYTES. *Continued*

Nitric acid		Sodium hydrate	
Grams HNO_3 per 100 cc. solution	Resistivity, ohms per cc.	Grams NaOH per 100 cc. sol.	Resistivity, ohms per cc.
6.2	3.205	2.5	9.266
12.4	1.845	5.0	5.076
18.6	1.449	10.0	3.205
24.8	1.302	15.0	2.890
31.0	1.023	20.0	3.058
49.6	1.577	30.0	4.950
6.2	2.016	40.0	8.621

ELECTRIC RESISTANCE OF SOME METALLIC OXIDES[1]

(Ohms per Cubic Centimeter)

Temperature deg. C.	Cr_2O_3	Fe_3O_4	SnO_2	NiO	CaO	Al_2O_3	SiO_2	MgO	ZrO
	All of these have a resistance of over 50,000 at room temperatures.								
400	6,000	11,750	900.0	3,000	......	......	......	......	......
450	2,450	4,300	400.0	1,115	......	......	......	......	......
500	1,250	2,450	235.0	490	......	......	......	......	......
550	1,000	1,450	125.0	400	......	......	......	......	......
600	850	1,200	68.0	330	......	......	......	......	......
650	1,175	845	56.0	240	......	......	......	......	......
700	1,010	710	47.0	195	......	......	......	......	......
750	950	510	42.0	121	......	......	......	......	......
800	690	357	37.0	220	......	......	......	......	......
850	668	290	32.0	280	......	......	......	......	......
900	520	210	28.0	190	......	......	......	......	......
950	395	162	25.5	81	......	......	......	......	......
1,000	345	127	24.0	115	......	......	......	......	......
1,050	335	117	23.0	93	......	......	......	......	......
1,100	330	105	22.25	45	......	......	......	......	......
Gas blow pipe...	......	......	......	......	550	190	590	600	580

It is safe to say that where the temperature exceeds 1500°C. it is impossible to obtain even approximately good electrical insulation by any means whatever. (NORTHRUP.)

All metallic oxides are solids and have a lower specific gravity than have the metals. They melt at higher temperatures than do the metals.

[1] *Zt. Electrochem.*, 1907, xiii, 589; as given in HOFMAN's "General Metallurgy."

Electrostatic Separation[1]

LIST OF MINERALS

›od conductors	Poor conductors
metals	Quartz
	Quartzite
ite	Calcite
›yrite	Limestone
	Porphyries
	Slates
enum	Sandstones
glance or chalcocite	Garnet
lance or argentite	Spinel
›pper or tetrahedrite	Blende or sphalerite
ılphides	Smithsonite ($ZnCO_3$)
›pper minerals	Barite
on minerals	Gypsum
lver minerals	Granite
anganese minerals	Fluorspar
.es	Most silicates
›nde	Most gangue rocks
ınds	Monazite

THE ANNEALED COPPER STANDARD

ılation from the French text adopted at the Inter-
l Electrical Commission, Berlin.

OF THE NATIONAL LABORATORIES CONCERNING AN INTERNATIONAL STANDARD FOR COPPER

I. Annealed Copper

ollowing values should be taken as normal for annealed ı copper.

20°C., the resistance of an annealed copper wire 1 meter d having a uniform cross-section of 1 sq. mm. is $1/58$ 0.017241 . . . ohm.

20°C., the density of annealed copper is 8.89 grams per ›ntimeter.

20°C., the coefficient of variation of resistance with ,ture of annealed copper, measured between potential ls rigidly attached to the wire (constant mass), is = $1/254.5$ per deg. C.

nsequently, it follows from (1) and (2) that, at 20°C., tance of an annealed copper wire of uniform cross-section long and having a mass of 1 gram is $(1/58) \times 8.89$, or . . . ohm.

II. Industrial Copper

e conductivity of annealed copper should be expressed emperature of 20°C. in percentage of that of standard ı copper, and ordinarily to a precision of 0.1 per cent.

[1] RICHARDS, "Ore Dressing," Vol. III.

2. The percentage conductivity of annealed industrial copper should be computed in accordance with the following rules:

(*a*) The observation temperature should not differ from 20°C. by more than 10°C.

(*b*) The resistance of a wire of industrial copper one meter long and of 1 sq. mm. cross section, increases 0.000068 ohm per deg. C.

(*c*) The resistance of a wire of industrial copper 1 meter long and of 1 gram mass, increases 0.00060 ohm per deg. C.

(*d*) The density of industrial annealed copper at 20°C. should be taken as 8.89 grams per cubic centimeter.

This value of the density should always be employed in the computation of conductivity in percentage of that of the annealed copper standard.

It follows from the above that if R is the resistance in ohms, at t deg. C. of a wire having a length of l meters and a mass of m grams, the resistance of a wire of the same copper 1 meter long and 1 sq. mm. cross-section will be

$Rm/(l^2 \times 8.89)$ ohms at t deg. C. and
$Rm/(l^2 \times 8.89) + 0.000068(20 - t)$ ohms at 20°C.
The percentage conductivity of this copper is thus

$$100 \times \frac{0.01724}{\dfrac{Rm}{l^2 \times 8.89} + 0.000068\,(20 - t)}$$

Similarly, the resistance of a wire of the same copper 1 meter long and 1 gram in weight is

Rm/l^2 ohms at t°C., and
$Rm/l^2 + 0.00060(20 - t)$ ohms at 20°C.

The percentage conductivity is thus

$$100 \times \frac{0.1533}{\dfrac{Rm}{l^2} + 0.00060(20 - t)}$$

NOTE 1. The standard values given in (*I*) are mean values deduced from a large number of tests. Among a number of samples of copper of normal conductivity, the density may differ from normal density up to 0.5 per cent., and the temperature coefficient of resistivity may differ from the normal up to 1 per cent.; but between the limits indicated in (*II*) these deviations will not affect the values of the computed percentage conductivity, if the resulting values are limited to four significant digits.

NOTE 2. The values above stated correspond to the following physical constants for standard annealed copper, all at the temperature of 0°C.

Density, 8.90 grams per cubic centimeter.
Coefficient of linear expansion 0.000017 per deg. C.
Resistivity, 1.5879[1] microhm-cm.

Volume resistivity temperature-coefficient 0.00429[1] per deg. from and at 0°C.
Resistance temperature coefficient at constant mass, 0.00427 $\frac{1}{234.5}$ per deg. C. from and at 0°C.

Kelvin's Rule for Power Transmission

The most economical section of conductor is that for which annual interest on capital outlay is equal to the annual cost energy wasted.

Copper Wire Table

olid wires are not made larger than No. 0000. A solid wire larger than o. 3 is infrequently used, and the constants for wires larger than a No. 3 given for stranded wires. Although wires are sometimes used as large ,000,000 circular mils, wires larger than 1,000,000 circular mils are not mon, and are omitted from the table. The carrying capacities are those cribed by the National Electrical Code.

Gage umber	Area in circular mils	Resistance in ohms per 1000 ft. at 25°C.	Carrying capacity in amperes		Weight in pounds per 1000 ft.
			Rubber insulation	Other insulation	
18	1,620	6.51	3	5	4.92
16	2,580	4.09	6	10	7.82
14	4,110	2.58	15	20	12.4
12	6,530	1.62	20	25	19.8
10	10,400	1.02	25	30	31.4
8	16,500	0.641	35	50	50.0
6	26,300	0.403	50	70	79.5
5	33,100	0.320	55	80	100.0
4	41,700	0.253	70	90	126.0
3	52,600	0.201	80	100	159.0
2	66,400	0.163	90	125	205.0
1	83,700	0.129	100	150	258.0
0	106,000	0.102	125	200	326.0
00	133,000	0.0811	150	225	411.0
000	168,000	0.0643	175	275	518.0
0000	212,000	0.0510	225	325	653.0
	250,000	0.0432	240	350	772.0
	300,000	0.0360	275	400	926.0
	400,000	0.0270	325	500	1,240.0
	500,000	0.0216	400	600	1,540.0
	600,000	0.0180	450	680	1,850.0
	700,000	0.0154	500	760	2,160.0
	800,000	0.0135	550	840	2,470.0
	900,000	0.0120	600	920	2,780.0
	1,000,000	0.0108	650	1,000	3,090.0

These two numerical values will probably be changed to 1.5880 and 428 by the National Physical Laboratories. Since reference is made usively to the values at 20°C. when measuring and stating percentage luctivity, these physical constants for 0°C. are of secondary importance ngineering.

Properties of Resistor Wires[1]

Material	Composition	Resistivity, 20°C.		Maximum Working temp., °C.
		Microhm-cm.	Ohms, mil. ft.	
Copper	Annealed	1.724	10.37	260
German silver	Cu 58, Ni 18, Zn 24	33.3	200.0	260
Manganin	Cu 84, Ni 4, Mn 12	41.4 – 73.8	249.0– 443.0	100
Monel metal	Cu, Ni	42.6	256.0	480
Therlo	Cu, Mn, Al	46.7	280.0	200
German silver	Cu 50, Ni 30, Zn 20	48.2	290.0	....
Advance	Cu, Ni	48.8	294.0	370
Ia Ia	Cu, Ni	49.0	295.0	....
Raymur	Cu, Ni	49.0	295.0	....
Constantin	Cu 60, Ni 40	50.0	300.0	....
Tico	Nickel steel	85.9	517.0	....
Phenix	Nickel steel	87.0	524.0	540
Climax	Nickel steel	87.2	525.0	540
Calido	Ni - Cr	95.5	575.0	1090
Tophet	Ni - Cr	96.0	580.0	....
Nichrome	Ni - Cr	99.6	600.0	900
Nichrome II	Ni - Cr	109.5	660.0	1100
Calorite	Ni - Cr	119.5	720.0	870

Fusing Currents for Copper Wire

The following table has been tested for copper-wire fusing currents and was found to be closely correct for average conditions, according to the *Electrical Review*.

Size wire, B. & S.	Fusing current, ampere	Size wire, B. & S.	Fusing current, ampere
30	10	18	80
28	15	17	100
26	20	16	120
25	25	15	140
24	30	14	160
22	40	13	200
21	50	12	240
20	60	11	280
19	70	10	330

If heat be developed in an electrical conductor faster than it can be dissipated from its surface by radiation and convection, the temperature will rise. The allowable rise in temperature is one of the limiting features of the current-carrying capacity of any conductor, since the rate at which heat will be dissipated will depend upon many conditions, such as the size and structure of the conductor, the kind and amount of insulation, if any, and the location with respect to other bodies. It is not possible to give any general definite rule for carrying capacity that will be true for all conditions.

[1] Standard Electrical Handbook.

The general subject of fusing currents for copper wire was investigated by W. H. Preece, who developed the formula: $I = ad^{\frac{3}{2}}$ where I is the fusing current in amperes, d is the diameter of the wire in inches, and a is a constant depending on the material. He found the following values for a.[1]

Copper	10,244	Iron	3,148
Aluminum	7,585	Tin	1,642
Platinum	5,172	Solder (2 Pb : 1 Sn)	1,318
German silver	5,230	Lead	1,379
Platinoid	4,750		

Wire Resistance Table[1]

Gage No. B. & S.	Diam. in mils, 20°C.	Cross-section at 20°C., sq. in.	Copper[1,2] ohms per 1000 ft.	Aluminum,[3] ohms per 1000 ft.
0000	460.0	0.1662	0.04901	0.0804
00	364.8	0.1045	0.07793	0.128
1	289.3	0.06573	0.1239	0.203
2	257.6	0.05213	0.1563	0.256
4	204.3	0.03278	0.2485	0.408
6	162.0	0.02062	0.3951	0.648
8	128.5	0.01297	0.6282	1.03
10	101.9	0.008155	0.9989	1.64
12	80.81	0.005129	1.588	2.61
14	64.08	0.003225	2.525	4.14
16	50.82	0.002028	4.016	6.59
18	40.30	0.001276	6.385	10.5
20	31.96	0.0008023	10.15	16.7
22	25.35	0.0005046	16.14	26.5
24	20.10	0.0003173	25.67	42.1
26	15.94	0.0001996	40.81	67.0
28	12.64	0.0001255	64.90	106.0
30	10.03	0.00007894	103.2	169.0
32	7.95	0.00004964	164.1	269.0
34	6.305	0.00003122	260.9	428.0
36	5.000	0.00001964	414.8	689.0
38	3.965	0.00001235	659.6	1080.0
40	3.145	0.000007766	1049.0	1720.0

Sparking Distances in Electrical Installations.—A mass of reliable data is now available concerning sparking distance between electrodes of simple geometrical form (needle points, disks, spheres, etc.), under various conditions, but little infor-

[1] "Standard Electrical Handbook."
[2] Standard annealed, at 20°C.
[3] Hard drawn, at 20°C.

mation has hitherto been available concerning sparking distances between metallic conductors and walls in workshops and on switchboards, etc. This problem, which is obviously of great practical importance was recently investigated by GINO REBORA (see also Atti dell' Associazione Elettrot. Italiana No. 31,913), and the first result deduced was the fact that a grain of dust or a fine hair or fiber would often suffice to start discharge from a high-tension conductor. A point or angularity in a conductor may cause a discharge to occur which would otherwise require 30 per cent. higher pressure than that actually operative; it is therefore very desirable that all metal subject to high-tension current should be as free as possible from points and angularities of any kind. The black lines frequently seen on switchboards and walls behind high-tension conductors reveal the presence of sustained feeble discharges which bombard the surface near the conductor with particles of dust.

From observations made in 30 installations, working at pressures between 3000 and 110,000 volts, REBORA derives a curve showing the minimum safe distance between conductor and earthed walls or metal covers, etc. As shown by the following data, his limits are rather less stringent than those recommended (but not always observed) by the G. E. C.:

P. D.		20	40	60	80	100	Kilovolts
Minimum distance between conductor and earth..........	Rebora	100	200	330	450	590	Mm.
	G. E. C.	150	300	450	620	770	Mm.

As regards the effective height of porcelain insulators of pylon form, used as intermediate insulators on distribution boards, etc., this height increases almost linearly at the rate of 5 or 5½ mm. per kilovolts for pressures up to 80 kv., and then increases more rapidly, to a total of 580 mm. for 100 kv. and 930 mm. for 130 kv. In deriving these data, MAGRINI, A. E. G., and RICHARD GINORI insulators were tested.

In the course of investigations conducted in the Ecole Polytechnique de Milan with a view to determining the laws of discharge between conductor and masonry, etc., copper wires, 2, 4, 5, 6 and 8 mm. in diameter, a bar 3 × 10 mm., and a brass tube $^{23}\!/_{22}$ mm. in external and internal diameter were used. As second electrodes were employed in turn walls of cement, stone, hollow brick, eternite, and metal frameworks. The maximum testing pressure available was 100 kv. at 42 cycles per second. When the conductor under test was pointed straight at the wall, breakdown occurred at 20 per cent.—25 per cent. lower P. D. (for separations of 100 to 250 mm.) than would be required to produce discharge between needle points the same distance apart. This is a result of great practical importance, since live metal parts are frequently so arranged in high tension installations as to produce reductions in the factor of safety.

Thermoelectricity[1]

When two different metals are brought into contact so that he two junctions are at different temperatures, there will usually be a slight current of electricity produced. The effective lectromotive force is

$$\text{volts} = \frac{(T_2 - T_1)\left[(B' - B'') + (C' - C'')\left(\frac{T_2 + T_1}{2}\right)\right]}{100{,}000{,}000}$$

'here T_2 and T_1 are the temperatures of the junctions, and ? and C constants as given in the following table:

Metal	B	C	Metal	B	C
:on	+1734	−4.87	Silver	+214	+1.50
teel	+1139	−3.28	Gold	+283	+1.02
oft platinum	+ 61	−1.10	Copper	+136	+0.95
[ard platinum	+ 260	−0.75	Lead	0	+0.00
Iagnesium	+ 244	−0.95	Tin	− 43	+0.55
ierman silver	+1207	−5.12	Aluminum	− 77	+0.39
inc	+ 234	+2.40	......	......	......

The behavior of nickel is anomalous. Antimony and bisıuth produce the greatest current of any two metals, but here gain, the constants vary greatly according to the absolute emperatures of the junctions.

Penetrating Power of X-rays[2]

Substance	Specific gravity	Transparency	Substance	Specific gravity	Transparency
Vater	1.00	1.000	Copper	8.92	0.084
.luminum	2.67	0.380	Silver	10.24	0.070
ilass	2.70	0.340	Lead	11.39	0.055
'in	7.29	0.118	Mercury	13.59	0.044
inc	7.16	0.116	Gold	19.63	0.030
ron	7.78	0.101	Platinum	21.53	0.020
lickel	8.51	0.095	......	......	......

Specific Gravity Tables

The following tables give the average specific gravities of ıost solids and liquids of importance in mining and metallurgy. 'here are separate tables for water, mercury, gases and the most mportant minerals.

Comparison of Standards.—Hydrogen, air and water are the hree standards commonly used in the determination of the pecific gravity of gases, liquids and solids. The relative .ensities of these standards are as follows:

Air (dry) is 14.418 times as heavy as hydrogen, at the same emperature and pressure, volume for volume.

Water (max. density, 4°C.) is 773 times as heavy as dry air t 30°F., bar. 29.92 in.; and 815 times as heavy as dry air at 0°F., bar. 30 in., volume for volume.

[1] "Encyclopedia Americana," Vol. XV, "Thermoelectricity."

[2] The wave length of X-rays is apparently about 10^{-9} to 10^{-8} cm. The able is from the *General Electric Review*.

SPECIFIC GRAVITIES AND UNIT WEIGHTS OF SOLIDS AND LIQUIDS

Substance	Average sp. gr. (water = 1)	Average weight (lb. per cu. ft.)
Alcohol, pure at 20°	0.789	49.2
commercial	0.834	52.1
Aluminum (cast)	2.56–2.71	164.0
(rolled)	2.66	166.0
Antimony	6.71	419.0
Argon (liquid, − 185°)	1.4	87.3
Arsenic (amorphous)	5.71	356.0
(crystallized)	5.73	358.0
(molten)	5.71	356.0
Asbestos	3.2	200.0
Ashes (packed)	0.72	45.0
Asphalt (1 to 1.8)	1.4	87.0
Barium	3.78	236.0
Beryllium	1.93	120.0
Bismuth (com'l)	9.74–9.92	614.0
(distilled)	9.78	611.0
(molten)	10.04	627.0
Boron	2.45	153.0
Brass, cast (7.8 to 8.4) 70 Cu, 30 Zn	8.1	506.0
rolled, 70 Cu, 30 Zn	8.4	524.0
Brick (fire)	....	140–150
(soft)	....	100.0
Brickwork, masonry (1.8 to 2.3)	....	110–140
Bromine (at 0°C.)	3.187	199.0
Bronze (8.7 to 8.9)	8.8	550.0
Cadmium	8.60–8.70	540.0
(molten)	7.99	499.0
Caesium	1.87	117.0
Calcium	1.85	115.0
Carbon disulphide	1.29	80.5
Cement (Portland, loose)	....	78–102
(American, loose)	....	50–60
Cerium	6.68	417.0
Chalk	2.5	156.0
Charcoal	....	13.0
Chromium	6.52–6.73	414.0
Clay (1.8 to 2.6)	2.2	137.3
Coal, anthracite (1.3 to 1.7)	1.5	93.6
bituminous (1.2 to 1.5)	1.3	81.15
cannel, gas coal (1.18 to 1.28)	1.23	76.78
lignite, brown coal	1.1	68.67
Cobalt	8.50–8.80	540.0
Coke, loose piled	....	20–30
Concrete	2.3	144.0
Copper, cast (8.6 to 8.8)	8.7	543.0
deposited	8.92	557.0
molten	8.22	513.0
rolled (8.8 to 8.95)	8.9	556.0
Cork	0.24	14.98
Diamond	3.52	....
Earth, dry, loose to well rammed	....	76–95
moist, loose to well rammed	....	78–96
wet, flowing mud	....	105–115
Emery	4.0	250.0
Erbium	4.97	310.0
Ethyl ether	0.735	45.9
Gallium	5.92	370.0
Germanium	5.47	335.0

IC GRAVITIES AND UNIT WEIGHTS OF SOLIDS AND LIQUIDS

Substance	Average sp. gr. (water = 1)	Average weight (lb. per cu. ft.)
	2.52	157.0
' flint)	2.93	200.0
	1.26	88.7
.25 to 19.37)	19.31	....
ed)	19.27	1203.0
(2.56 to 2.88)	2.72	170.0
(average value)	2.2	137.0
oose	....	95–120
ne (trap)	....	170–200
ground or calcined, loose	....	56.0
aken	....	64.0
ined	....	130–150
ide	....	200–220
	0.92	57.5
	4.95	309.0
	7.12	444.0
	22.42	1400.0
t gray, 7.08, white	7.6	450.0
n)	6.88	429.0
	7.68	480.0
it, sheet (7.6 to 7.9)	7.8	485.0
im	6.15	384.0
.3 to 11.47)	11.35	710.0
n)	10.64	664.0
	....	75.0
icklime)	1.5	93.75
, loose (66 lb. per bushel)	....	53.0
e	2.7	168.0
	0.59	36.8
	....	65–100
im	1.74	109.0
se	7.39[2]	461.0
2.5 to 2.8)	2.65	160–180
	....	100–140
(32°F.)	13.5955	850.0
	13.555	847.0
– 40°F.	15.632	976.0
	2.8	175.0
num	8.60	537.0
	....	90–105
um	6.956	434.0
	8.9	556.0
	8.86	553.0
	12.7	793.0
.0 to 0.975), weight given in pounds gallon:		
l. lard	0.916	7.64
n (pure)	0.880	7.34
e	0.925	7.72
il, petroleum (crude)	0.77–1.06	....
lene	0.700	5.84
sene (coal oil)	0.800	6.68
itha	0.730	6.09
ble, cottonseed	0.923	7.70
ed (boiled)	0.933	7.79
(raw)	0.780	6.51
	0.917	7.65
(colza)	0.915	7.63

lso special table on p. 174.
ı as 8.30 by NYSTROM.

SPECIFIC GRAVITIES AND UNIT WEIGHTS OF SOLIDS AND LIQUI

Substance	Average sp. gr. (water = 1)	Average weight (lb. per cu. f
Osmium	22.48	1403.0
Palladium	11.90	743.0
Peat (dry, unpressed)	....	20–30
Phosphorus (red)	2.34	146.0
(white)	1.837	115.0
Pitch	1.155	72.0
Platinum wire	21.5	1342.0
Potassium	0.875	54.9
Præseodymium	6.475	404.0
Pumice	....	50–60
Quartz	2.65	165.0
(broken)	....	94.0
Rhodium	12.60	787.0
Rosin	1.1	68.67
Rubidium	1.52	94.9
Ruthenium	12.06	753.0
Salt	....	45.0
Samarium	7.75	484.0
Sand (dry)	....	100.0
(wet)	....	130.0
Sandstone (2.1 to 2.7)	2.4	150.0
Selenium (gray metal)	4.8	293.0
(red)	4.47	279.0
Shale (2.4 to 2.8)	2.6	162.0
Silicon (amorphous)	2.00	125.0
(crystallized)	2.195	137.0
Silver (cast)	10.75	671.0
(electrolytically deposited)	10.53	655.0
(molten)	9.51	594.0
Slate (2.7 to 2.9)	2.7	169.0
Snow (fresh, dry)	....	5–12
(wet)	....	15–50
Soapstone	....	166.0
Soda ash	1.2	74.0
Sodium	0.972	60.7
Steel (7.69 to 7.93)[1]	7.85	490.0
Strontium	2.54	159.0
Sugar	1.6	....
Sulphur	1.96–2.07	125.0
Tallow	0.94	58.7
Tantalum	16.6	1036.0
Tar	1.0	62.5
Tellurium	6.25	390.0
Thallium	11.85	740.0
Thorium	12.16	759.0
Tin (cast)	7.29	459.0
(molten)	7.02	438.0
Titanium	4.87[3]	304.0
Traprock	3.0	187.0
Tungsten	18.7–19.10	1180.0
Uranium	18.69	1667.0
Vanadium	5.50	337.0
Water[2] (max. density 4°C.)	1.0	62.428
(pure, 62°F.)	0.999	62.366
(pure, 212°F.)	0.958	59.806
sea, average	1.028	64.176
Wax (bees)	0.97	60.5

[1] Pure and soft. The specific gravity decreases as the carbon increases
[2] See special table on p. 173 for water.
[3] Given in HOFMAN'S "General Metallurgy" as 5.30.

NOTE.—Most of the constants for the chemical elements are taken from t "Annuaire pour 1915 der Bureau des Longitudes," omitting the last figure.

For the specific gravities of the metals, there are usually two values give The low figures are usually those of cast metals, the high ones of metal eith finely rolled or drawn into fine wire.

Substance	Average sp. gr. (water = 1)	Average weight (lb. per cu. ft.)
ɔd, dry, seasoned:		
sh, white	0.6–0.8	38.0
irch		41.0
edar, white		23.0
red		35.0
herry		42.0
hestnut		41.0
lm		35.0
bony		76.0
ir, Douglas		20.0
emlock		25.0
ickory		53.0
'ahogany, Spanish		53.0
Honduras		35.0
'aple		49.0
ak, live		59.0
white	0.8	48.0
black, jack, etc		35–45
ine, white		25.0
yellow, Northern	0.52	34.0
Southern		45.0
ɔplar (cottonwood)		33.0
ɔruce		25.0
'camore		37.0
'alnut		37.0
ium	3.8	237.0
:	7.15	446.0
ıolten)	6.48	405.0
onium	6.25	390.0

DENSITIES OF WATER AT DIFFERENT TEMPERATURES[1]

'C.	0.999868	15	0.999126	29	0.995971
	0.999927	16	0.998970	30	0.995673
	0.999968	17	0.998801	31	0.995367
	0.999992	18	0.998622	40	0.99224
	1.000000	19	0.998432	50	0.98807
	0.999992	20	0.998230	60	0.98324
	0.999968	21	0.998019	70	0.97781
	0.999929	22	0.997797	80	0.97183
	0.999876	23	0.997565	90	0.96534
	0.999808	24	0.997323	100	0.95838
	0.999727	25	0.997071	110	0.951
	0.999632	26	0.996810	150	0.917
	0.999525	27	0.996539	200	0.863
	0.999404	28	0.996259	250	0.79
	0.999271			300	0.70

The above tables are founded on THIESSEN's figures as given in "Annuaire r 1914, Bureau des Longitudes." Other authorities give values somewhat er his.

Properties of Water[1]

Temperature, deg. F.	Weight in pounds per cubic foot	Relative volume	Temperature, deg. F.	Weight in pounds per cubic foot	Relative volume
32.0	62.418	1.00011	100	62.02	1.00686
39.1	62.425	1.00000	120	61.74	1.01138
50.0	62.41	1.00025	140	61.37	1.01678
60.0	62.37	1.00092	160	60.98	1.02306
62.0	62.355	1.00110	180	60.55	1.03023
70.0	62.31	1.00197	200	60.07	1.03819
80.0	62.23	1.00332	210	59.82	1.04246
90.0	62.13	1.00496	212	59.76	1.04332

For sea water, multiply the above by 1.026. One U. S. gallon of water at 62°F. weighs 8.3356 lb. Water freezes at 32°F.; is at its maximum density at 39.1°F., British standard for sp. gr., 62°F.; boiling point at sea-level, 212°F.

[1] From Pierce and Carver's "Formulas and Tables for Engineers."

Payne's Table for Water in Air[1]

The following table will give the amount of water weighed in air with brass weights necessary to fill a liter flask to the 1000 cc. mark at 20°C.

Temperature of water	Apparent weight	Temperature of water	Apparent weight
15	998.0	24	996.6
16	997.9	25	996.3
17	997.7	26	996.1
18	997.6	27	995.9
19	997.5	28	995.6
20 (standard)	997.3	29	995.4
21	997.1	30	995.1
22	996.9	31	994.9
23	996.8	32	994.5

[1] Foulk's "Manual of Qualitative Analysis."

Densities of Mercury[1]

Temperature deg. F.	Pounds per cubic inch	Temperature deg. F.	Pounds per cubic inch	Temperature deg. F.	Pounds per cubic inch
0	0.4928	40.0	0.4907	80	0.4888
10	0.4923	50.0	0.4903	90	0.4883
20	0.4918	58.1	0.4899	100	0.4878
30	0.4913	60.0	0.4898	110	0.4873
32	0.4912	70.0	....	....	....

Temperature deg. C.	Grams per cc.	Temperature deg. C.	Grams per cc.	Temperature deg. C.	Grams per cc.
−20	13.6450	40	13.4973	100	13.3518
−10	13.6202	50	13.4729	150	13.233
0	13.5955	60	13.4486	200	13.068
10	13.5708	70	13.4243	250	12.998
20	13.5462	80	13.4001	300	12.881
30	13.5217	90	13.3759	....	....

[1] Ellenwood's "Steam Charts."

Kirby's Table of Weights of Ore in Place[1]

Material	Weight per cubic foot		Cubic feet per ton	
	Theoretically,[2] pounds	Practically, pounds	Theoretically[2]	Practically
Galena	465	426	4.3	4.7
Pyrite	313	286	6.4	7.0
Blende	250	235	8.0	8.5
Hematite	303	267	6.6	7.5
Limonite	238	213	8.4	9.4
Dolomite	175	160	11.4	12.5
Limestone, andesite, syenite	168	154	11.9	13.0
Vein quartz, granite and granitic rocks	168	148	11.9	13.5
Clay, quartz, porphyry, trachytes, rhyolites	163	136	12.3	14.5
Vein quartz, with 15 per cent. galena	187	164	10.7	12.2
Vein quartz, with 15 per cent. pyrites	180	160	11.1	12.5
Vein quartz, with 10 per cent. hematite	170	155	11.4	12.9

[1] R. H. Richards, "Ore Dressing, Vol. II."
[2] Calculated from specific gravity of pure unaltered specimens.

McDonald's Table of Weights of Ore[1]

Material	Weight per cubic foot		Cubic feet per ton	
	In place, pounds	Broken, pounds	In place	Broken
Granite and porphyry	170	97	11.8	20.6
Gneiss	168	96	11.9	20.8
Greenstone and trap	187	107	10.7	18.7
Limestone	168	96	11.9	20.8
Slate	175	95	11.4	21.1
Quartz	165	94	12.1	21.3
Sandstone	151	86	13.2	23.3
Earth in bank	111	....	18.0	....
Earth dry and loose	....	74	....	27.0
Clay	118	....	17.0	....
Sand	80	....	25.0	....

[1] Probably for ore as delivered to mill.

Weight of Rock and Sand[1]

	Cubic feet per ton	Weight in pounds per cubic foot
Sulphide ore in place	11 to 13	154 to 182
Sulphide ore broken	15 to 18	111 to 133
Oxidized ore in place	14 to 18	111 to 143
Oxidized ore broken	22 to 24	81 to 91
Quartz in place (sp. gr. = 2.65)	12.0	165.0
Quartz broken	21.0	94.0
Earth in bank	18.0	111.0
Earth, dry and loose	27.0	74.0
Clay	17.0	118.0
Loose sand	25.0	80.0
Mill tailing[2] (sp. gr. 2.7)		
Sand collected under water	21.5	93.0
Transferred sand (before leaching)	26.0	77.0
Leached sand (after transferring)	24.0	83.3

[1] From MacFarren's "Cyanide Practice." "Mining and Scientific Press," San Francisco, Calif.
[2] W. A. Caldecott, *Journ. Chem., Met. and Min. Soc. of S. A.*, Oct., 1910.

DENSITY AND HARDNESS OF MATERIALS[1]

	Specific gravity	Hardness
Acids and oxides:		
Arsenious acid, As_2O_3	3.69–3.70	1.5
Boric acid, $B(OH)_3$	1.48	1.0
Titanic acid, anatase, TiO_2	3.88	5.5–6.0
brookite, TiO_2	4.14	5.5–6.0
rutile, TiO_2	4.28	6.0–6.5
Corundum, Al_2O_3	3.90–4.02	9.0
Cuprite, Cu_2O	5.99	3.75
Diaspore, $Al(OH)_3 \cdot Al_2O_3$	3.37	6.5
Tin oxide (cassiterite), SnO_2	6.30–7.10	6.5
Melaconite (black copper), CuO	6.20–6.30	3.0–4.0
Hematite, Fe_2O_3	4.54–5.28	6.0
Magnetite, Fe_3O_4	4.94–5.18	5.5
Ferric oxide (hydrated) limonite	3.60–4.00	5.5
Ice at 0°C	0.92	....
Magnesia (periclase), MgO	3.67	6.0
Magnesia (hydrated, brucite), $Mg(OH)_2$	2.35	2.5
Manganese oxide, braunite,	4.75	6.0–6.5
hausmannite, Mn_3O_4	4.72	5.0–5.5
pyrolusite, MnO_2	4.82–4.97	2.0
Silica, agate, SiO_2	2.58–2.62	6.0
quartz, SiO_2	2.65	7.0
Opal (hydrated silica)	2.03–2.09	5.5–6.5
Uranium oxide (pitchblende)	6.01–8.07	5.5
Zincite, ZnO	5.57	4.0–4.5
Aluminates:		
Spinel, $MgO \cdot Al_2O_3$	3.55	8.0
Anorthite, $Ca_2Al_4Si_4O_{16}$	2.7	6.0–7.0
Antimonides:		
Breithauptite, $NiSb$	7.54	5.5
Antimonite, Sb_2S_3	4.57	2.5
Arsenides:		
Cobalt arsenide, smaltite, $(Co,Ni)As_2$	6.41	5.5
Copper arsenide, domeykite, Cu_3As	7.75	3.0–3.5
Nickel arsenide, niccolite, $NiAs$	7.72	5.5
Borates:		
Boracite, $Mg_7Cl_2B_{16}O_{30}$	2.91–2.97	5.0–7.0
Borax, $Na_2B_4O_7 \cdot 10H_2O$	1.72	2.0
Bromides:		
Silver bromide, $AgBr$	5.80–6.00	2.0–3.0
Carbonates:		
Aragonite, $CaCO_3$	2.93–2.94	3.5–4.0
Azurite, $3Cu_3C_2O_7 \cdot 7H_2O$	3.70–3.83	4.0
Calcite, $CaCO_3$	2.70–2.73	3.0–3.65
Cerussite, $PbCO_3$	6.57	3.25
Dolomite, $MgCa(CO_3)_2$	2.83–2.94	3.75
Malachite, $Cu_2CO_4 \cdot H_2O$	3.93	3.5
Magnesite, $MgCO_3$	3.0	3.5–4.5
Siderite, $FeCO_3$	3.83–3.88	3.5–4.0
Smithsonite, $ZnCO_3$	4.30–4.45	5.0
Stronianite, $SrCO_3$	3.60–3.71	3.5–4.0
Witherite, $BaCO_3$	4.28	3.5
Chlorides:		
Atacamite, $Cu_2(OH_3)Cl$	3.70	3.0–3.5
Calomel, Hg_2Cl_2	6.48	1.0–2.0
Carnallite, $KMgCl_3 \cdot 6H_2O$	1.6	1.0
Cerargyrite, $AgCl$	5.31–5.43	1.5
Rock salt, $NaCl$	2.26	2.5
Sylvite, KCl	1.90–2.00	2.0
Chromates:		
Lead chromate, $PbCrO_4$	5.90–6.10	2.5–3.0
Chromite, $FeCr_2O_4$	4.32–4.50	5.5

[1] From "Annuaire pour 1914, par le Bureau des Longitudes."

	Specific gravity	Hardness
Fluorides:		
Cryolite, Na_3AlF_6	2.96	2.5
Fluorite, CaF_2	3.14–3.19	4.0
Molybdates:		
Wulfenite, $PbMoO_4$	6.95	3.0
Niobates and Tantalates:		
Fergusonite, Y, Er, Ce, Nb, Ta, O	5.84	5.5–6.0
Niobite, $FeNb_2O_6$	5.60–6.00	6.0
Samarskite	5.54	5.0–6.0
Tantalite, $FeTa_2O_6$	7.03	6.0
Nitrates:		
Saltpeter, KNO_3	1.94	2.0
Phosphates:		
Apatite	2.90–3.20	5.0
Autunite	3.57	2.0–2.5
Monazite (Ce, La)PO_4	5.00–5.09	5.2
Pyromorphite, $Pb_5Cl(PO_4)_3$	6.59–7.05	3.5–4.0
Turquoise	2.52–2.80	6.0
Chalcolite	3.40–3.60	2.0–2.5
Silicates:		
Albite	2.60–2.62	6.0
Amphibole	2.92–3.59	5.5
Andalousite, Al_2SiO_5	3.14–3.16	7.5
Augite	3.20–3.50	5.0–6.0
Emerald (beryl)	2.67–2.75	7.5–8.0
Epidote	3.46	6.5
Feldspar orthoclase	2.50–2.59	6.0
albite	2.60–2.62	6.0
oligoclase	2.61–2.64	6.0
andesite	2.67–2.68	....
labradorite	2.70–2.72	6.0
anorthite	2.75	....
Gadolinite, $Be_2FeY_2Si_2O_{10}$	4.23–4.33	6.5–7.0
Granite	3.42–4.20	....
Hornblende	2.90–3.40	5.0–6.0
Hypersthene (Fe,Mg)SiO_3	3.36–3.42	5.0–6.0
Idocrase	3.29–3.43	6.5
Jadeite, $NaAl(SiO_3)_2$	3.28–3.35	6.5–7.0
Lapis-lazuli	2.50–3.04	5.0–5.5
Peridote	3.33–3.41	6.5–7.0
Phenacite, Be_2SiO_4	2.96	7.5–8.0
Olivine $(Mg,Fe)_2SiO_4$	3.30–3.50	6.0–7.0
Mica	2.70–3.10	2.0–2.5
Pyroxene, diopside	3.32	4.0–6.0
augite	3.30	5.5
hedenbergite	3.50	....
Quartz, SiO_2	2.65	7.0
Rhodonite	3.64	5.5–6.5
Serpentine	2.6	3.0–4.0
Sillimanite, Al_2OSiO_4	3.24	7.5
Thorite, $ThSiO_4$	4.19–5.22	4.5–5.0
Willemite, Zn_2SiO_4	4.01	5.0
Wollastonite, $CaSiO_3$	2.80–2.90	4.5–5.0
Zircon, $ZrSiO_4$	4.04–4.67	7.5
Hydrated silicates:		
Calamine, $Zn_2(OH)_2SiO_3$	3.35–3.50	5.0
Chrysocolla, $CuSiO_3 \cdot 2H_2O$	2.00–2.20	3.5
Halloysite	1.92–2.12	....
Kaolin	2.5	1.0
Magnesite, $H_4Mg_2Si_3O_{10}$	1.80–2.20	2.0–2.5
Pyrophyllite, $HAl(SiO_3)_2$	2.78	1.5
Talc	2.71	1.0
Thomsonite	2.38	5.0–5.5
Silicoborate:		
Tourmaline	3.04–3.20	7.0–7.5

	Specific gravity	Hardness
Silicochloride:		
Pyrosmalite	3.08	4.0–4.5
Sodalite	2.38–2.42	5.5–6.0
Silico-fluorides:		
Leucophane	2.97	4.0
Mica	2.71–3.13	2.0–3.0
Topaz	3.51–3.58	8.0
Siliconiobate:		
Wöhlerite	3.41	5.5–6.0
Sulphates:		
Anglesite, $PbSO_4$	6.26–6.30	3.0
Anhydrite, $CaSO_4$	2.90–2.96	3.0–3.5
Barite, $BaSO_4$	4.48–4.72	3.0
Celestite, $SrSO_4$	3.92–3.96	3.0–3.5
Epsomite, $MgSO_4 \cdot 7H_2O$	1.75	2.0–2.5
Glauberite, Na_2SO_4	2.64–2.85	....
Gypsum, $CaSO_4 \cdot 2H_2O$	2.33	2.0
Kainit, $MgSO_4 \cdot KCl \cdot 3H_2O$	2.1	2.5
Sulphides:		
Argentite, Ag_2S	7.24	2.5
Bismuthinite, Bi_2S_3	6.40	2.0
Blende (sphalerite), ZnS	4.09	3.5–4.0
Bornite, Cu_3FeS_3	4.40–5.50	3.0
Chalcocite, Cu_2S	5.78	2.75
Chalcopyrite, $CuFeS_2$	4.17	4.0–4.2
Cinnabar, HgS	8.12–8.20	2.5
Erubescite, Cu_3FeS_3	5.05	3.0
Galena, PbS	7.26–7.60	2.75
Greenockite, CdS	4.99	3.0–3.5
Marcasite, FeS_2	4.77–4.86	6.0–6.5
Millerite, NiS	5.65	3.5
Molybdenite, MoS_2	4.94	1.5
Orpiment, As_2S_3	3.45	1.75
Pyrite, FeS_2	4.85–5.04	6.0
Pyrrhotite, FeS	4.62	4.0
Realgar, AsS	3.64	2.0
Stibnite, Sb_2S_3	4.62	2.0
Sphalerite, ZnS	4.09	3.5–4.0
Sulph-antimonides:		
Bournonite, $PbCuSbS_3$	5.75–5.83	2.5–3.0
Jamesonite, $PbFeSb_6S_{14}$	5.61	2.5
Pyrargyrite, Ag_3SbS_3	5.86	2.5
Sulph-arsenides:		
Cobaltite, CoAsS	6.26–6.37	5.5
Enargite, Cu_3AsS_4	4.36	3.0
Mispickel, FeAsS	5.22–6.07	5.5–6.0
Proustite, Ag_3AsS_3	5.50	2.0–2.5
Tellurides:		
Nagyagite, Au, Pb, Sb, Te, S	6.68–7.20	1.0–1.5
Tetradymite, Bi, Te, S	7.41	1.5–2.0
Petzite $(Ag,Au)_2Te$	8.83	2.5–3.0
Sylvanite, $AuAgTe_4$	8.28	2.0
Titanates:		
Ilmenite, $FeTiO_3$	4.89	5.0–6.0
Tungstates:		
Scheelite, $CaWO_4$	6.07	4.5–5.0
Wolframite $(Fe,Mn)WO_4$	7.14–7.36	5.0–5.5
Vanadates:		
Descloizite	5.84	3.0–5.0
Vanadinite, $Pb_5Cl(VO_4)_3$	6.66–7.23	3.0
Combustibles:		
Anthracite	1.34–1.46	....
Asphalt	0.83–1.16	....
Bituminous	1.28–1.36	....
Lignite	1.10–1.35	....

The Principal Concentrating Ores and Gangues[1]

	Specific gravity	Hardness
Lead:		
Galena	7.26–7.60	2.0–3.0
Cerussite	6.57	3.75
Anglesite	6.26–6.30	3.0
Copper:		
Melaconite	6.0	3.0–4.0
Cuprite	3.99–4.02	....
Chalcocite	5.78	2.75
Bornite	4.40–5.50	3.0
Chalcopyrite	4.17	3.5–4.0
Malachite	3.93	3.5–4.0
Chrysocolla	2.00–2.20	2.0–4.0
Iron:		
Mispickel	5.22–6.07	5.5–6.0
Magnetite	4.94–5.18	5.5–6.5
Pyrite	4.85–5.04	6.0–6.5
Marcasite	4.77–4.86	6.0–6.5
Pyrrhotite	4.62	4.0
Zinc:		
Smithsonite	4.30–4.45	5.0
Sphalerite	4.09	3.5–4.0
Willemite	4.01	5.0
Gangues:		
Barite (heavy spar)	4.48–4.72	3.0–3.5
Manganese garnet	4.10–4.50	7.0
Iron garnet	3.90–4.40	7.0
Lime garnet	3.40–3.50	7.0
Fluorite (fluorspar)	3.14–3.19	4.0
Anhydrite (gypsum)	2.90–2.96	1.5–2.0
Dolomite	2.83–2.94	3.5–4.0
Quartz	2.50–2.80	7.0
Calcite	2.70–2.73	3.0
Kaolimite	2.40–2.60	1.0
Hematite	4.50–5.30	5.5–6.5
Serpentine	2.6	3.0–4.0
Spinel	3.50–3.60	8.0
Talc	2.50–2.80	1.0
Miscellaneous:		
Hornblende	2.90–3.50	5.0–6.0
Monazite	5.0	5.2
Pitchblende	6.4	5.5
Rutile	4.20–4.30	6.0–6.5
Thorianite	8.00–9.70	7.0
Thorite	4.6	....
Wolframite	7.10–7.90	5.0–5.5

[1] From MEGRAW's "Practical Data for the Cyanide Plant." For a longer table, based on acid radicals, see p. 176.

Specific Gravity and Absolute Weight of Gases

Gas	Formula	Molecular wt. 0 = 16	Weight of 1 liter in grams at 0°C. and 760 mm. pressure	Sp. gr. Air = 1	Wt. of 1 cu. ft. in lb. at 32° F. and 29.92 in. pressure
Acetylene	C_2H_2	26.016	1.1708	0.90561	0.07309
Air	....	....	1.2928	1.0000	0.08071
Aldehyde	C_2H_4O	44.032	1.9811	1.5324	0.12368
Ammonia	NH_3	17.034	0.7708	0.59623	0.04812
Alcohol, ethyl	C_2H_5OH	46.048	2.0862	1.6137	0.13024
Alcohol, amyl	$C_5H_{11}OH$	88.096	4.0696	3.1479	0.25406
Alcohol, methyl	CH_3OH	32.032	1.4483	1.1203	0.09042
Argon	Ar	39.88	1.7809	1.3776	0.11118
Arsine	AsH_3	77.984	3.4589	2.6755	0.21593
Benzene	C_6H_6	78.048	3.5821	2.7708	0.22362
Boron chloride	BCl_3	117.38	5.09	3.937	0.3177
Boron fluoride	BF_3	68.00	2.99	2.312	0.1867
Bromine	Br_2	159.84	7.1437	5.5258	0.44597
Butane	C_4H_{10}	58.08	2.65	2.050	0.1654
Cyanogen	C_2N_2	52.05	2.335	1.806	0.14577
Chlorine	Cl_2	70.92	3.222	2.4923	0.20114
Chlorine monoxide	Cl_2O	86.92	3.8820	3.0028	0.24235
Chlorine dioxide	ClO_2	67.96	3.0192	2.3354	0.18848
Carbon dioxide	CO_2	44.00	1.9768	1.5291	0.12341
Carbon monoxide	CO	28.00	1.2504	0.96720	0.07806
Carbonyl chloride	$COCl_2$	98.92	4.47	3.457	0.2791
Carbonyl sulphide	COS	60.07	2.721	2.1047	0.16987
Ethane	C_2H_6	30.048	1.3562	1.0496	0.08467
Ethylene	C_2H_4	28.032	1.2609	0.97532	0.07872
Fluorine	F_2	38.00	1.635	1.2647	0.1021
Helium	He	4.002	0.1782	0.1378	0.01112
Hydrobromic acid	HBr	80.928	3.50	2.707	0.2185
Hydrochloric acid	HCl	36.468	1.6392	1.26794	0.10233
Hydrofluoric acid	HF	20.008	0.9220	0.71318	0.05756
Hydriodic acid	HI	127.928	3.657	2.8287	0.22830
Hydrogen	H_2	2.016	0.08987	0.069516	0.005610
Hydrogen arsenide	AsH_3	77.984	3.4589	2.67755	0.21593
Hydrogen selenide	H_2Se	81.216	3.628	2.80639	0.22650
Hydrogen sulphide	H_2S	34.086	1.539	1.1904	0.07431
Hydrogen phosphide	PH_3	34.064	1.5293	1.18293	0.09547
Hydrogen telluride	H_2Te	129.516	5.80	4.486	0.3621
Hydrocyanic acid	HCN	27.018	1.226	0.9483	0.05920
Iodine	I_2	253.84	11.271	8.7183	0.70363
Krypton	Kr	82.92	3.708	2.8682	0.23148
Methane	CH_4	16.032	0.7168	0.55446	0.04475
Neon	Ne	20.0	0.9002	0.69634	0.05620
Methyl chloride	CH_3Cl	50.484	2.3045	1.78261	0.14387
Mercury	Hg	200.6	9.0210	6.97850	0.56317
Nitrogen	N_2	28.02	1.2057	0.93265	0.07527
Nitrous oxide	N_2O	44.02	1.9782	1.53021	0.12350
Nitric oxide	NO	30.01	1.3402	1.03669	0.08367
Nitrogen tetroxide	N_2O_4	92.02	4.1133	3.18178	0.25679
Nitrogen tetroxide	NO_2	46.01	2.0567	1.59092	0.12840
Nitrosyl chloride	NOCl	65.47	2.9253	2.26282	0.18262
Oxygen	O_2	32.00	1.4291	1.02803	0.08921
Phosphine	PH_3	34.064	1.5193	1.09788	0.09487
Phosphorus	P_4	124.16	5.6318	4.35639	0.35158
Propane	C_3H_8	44.064	1.9660	1.558	0.12273
Propylene	C_3H_6	42.048	1.8783	1.45293	0.11726
Silicon fluoride	SiF_4	104.3	4.6603	3.60490	0.29093
Sulphur dioxide	SO_2	64.07	2.9266	2.26390	0.18264
Xenon	Xe	130.2	5.851	3.7524	0.36527
Radium emanation	Nt	222.4	9.727	7.5241	0.60724
Water	H_2O	18.016	0.8063	0.6237	0.050336

The column headed Weight of 1 liter in grams, etc., is mainly based upon the tables in "Annuaire pour 1914, Bureau des Longitudes" and in the "Annual Tables" published by the International Congress of Applied Chemistry. Other data are compiled from various sources. There is a wide variation in the results for these constants, even between the work of two supposedly equally qualified workers. For that reason I have, in several instances, cut out some of the last decimal places. Unquestionably this variation is caused by the effect of surface condensation of gas films on the apparatus worked with. The determination of these constants for gases is by no means a simple problem. So far as possible, the values are those obtained experimentally, and are not simply calculated from atomic weights. In the cases of such substances as mercury, water, etc., the values at 0° and 29.92 in. of mercury pressure are purely theoretical. The experiments for the determination of the constants have been made at higher temperatures and the values in the table calculated from the equation $pv = RmT$.

The number of molecules per cubic centimeter of gas under standard conditions is about 27.09×10^{18}.

Velocity of electrons, 2.36×10^{10} to 2.85×10^{10} cm. per second.

The value of the gas constant in the formula for perfect gases has been calculated by M. D. Berthelot for "Annuaire pour 1914, Bureau des Longitudes." He considers a large number of gases and obtains for the mean value in

$$pv = RT$$
$$R = 0.08207$$

A gram molecule of gas at 0°C. and 760 mm. is 22,380 cc.

If a gas be expanded or compressed so quickly that no heat is either absorbed or given off, then $pv^{1.406} = k$.

Critical Temperatures and Pressures[1]

The critical temperature of a gas is that temperature above which no pressure suffices to produce a liquid. The pressure at which a gas at the critical temperature begins to become a liquid is known as the critical pressure:

[1] "Annuaire par 1914, Bureau des Longitudes."

Substance	Critical tempera-ture, deg. C.	Critical pressure, atmos.	Critical density calculated
Elements:			
Argon	−122.44	48.0	...
Bromine	302.2	...	...
Chlorine	146.0	83.9	0.547
Helium	−267.84	2.26	...
Hydrogen	−241.1	11.0	0.043
Iodine	512.0	...	...
Krypton	− 62.5	41.24	...
Mercury	1270.0	...	...
Neon	<205.0	29.0	...
Nitrogen	−145.1	33.6	0.299–0.296
Oxygen	−118.8	50.8	0.400
Xenon	14.7	43.5	...
Inorganic substances:			
Ammonia, NH_3	131.0	113.0	...
Carbon monoxide, CO	−139.5	35.5	0.326
Carbon dioxide, CO_2	31.1	73.0	0.460
Carbon disulphide	273.05	72.87	0.4408
Carbonyl sulphide, COS	105.0	...	...
Germanium tetrachloride, $GeCl_4$	276.9	38.0	...
Hydrochloric acid, HCl	51.8	83.6	0.462
Hydriodic acid, HI	150.7	...	...
Hydroselenic acid, H_2Se	137.0	91.0	...
Nitric oxide, N_2O_2	− 93.5	71.2	...
Nitrogen monoxide, N_2O	36.5	71.95	0.524
Nitrosyl chloride, NOCl	167.0	...	...
Phosphine, PH_3	51.3	64.5	...
Phosphorus trichloride, PCl_3	285.5	...	0.534
Silicon hydride, SiH_4	− 0.5	100.0	...
Silicon tetrachloride, $SiCl_4$	221.0	...	...
Sulphur dioxide, SO_2	157.0	78.0	0.520
Sulphuretted hydrogen, H_2S	100.4	89.3	...
Tin tetrachloride, $SnCl_4$	318.7	36.95	...
Water, H_2O	364.3	194.6	...
Organic substances:			
Acetylene, C_2H_2	35.5	61.7	...
Alcohol (ethyl), C_2H_5OH	243.1	62.96	0.276
Benzene, C_6H_6	288.5	47.89	0.305
Carbon tetrachloride, CCl_4	283.15	44.97	0.558
Ethane, C_2H_6	32.1	49.0	...
Ethylene, C_2H_4	9.5	50.8	0.210
Naphthalene, $C_{10}H_8$	468.2	39.2	...
Methane, CH_4	− 81.8	54.9	0.145
Pentane, C_5H_{12}	197.2	33.0	0.232
Phenol, C_6H_5OH	419.2	...	...
Toluene, C_7H_8	320.6	41.6	0.287

How to Generate the Various Gases

Acetylene.—Best generated from calcium carbide and water ($CaC_2 + 2H_2O = Ca(OH)_2 + C_2H_2$). Can also be prepared by the incomplete combustion of coal gas, or by the action of acetylene bromide on alcoholic potash ($C_2H_4Br_2 + 2KOH = C_2H_2 + 2H_2O + 2KBr$). Can also be bought compressed in cylinders.

Ammonia.—Best generated by the action of calcium oxide on ammonium chloride. Can be bought compressed in cylinders.

Argon.—Can be obtained by depriving air of oxygen with phosphorus, then absorbing the nitrogen by red-hot magnesium.

Arsine.—The gas may be obtained pure by the following reaction:

$$Sn_3As_2 + 6HCl = 3SnCl_2 + 2AsH_3$$

It is also formed when any arsenious compound comes into contact with nascent hydrogen, which reaction forms the basis for the well-known Marsh test. The other hydride of arsenic, As_2H_4, is a solid.

Bromine.—Best generated by heating the easily purchased liquid bromine.

Carbon Dioxide.—Best made by the action of hydrochloric acid on marble or sulphuric acid on sodium carbonate. Can also be bought compressed.

Carbon Monoxide.—Best made pure by heating oxalic acid with concentrated sulphuric acid and absorbing the carbon dioxide in calcium hydrate emulsion:

$$C_2H_2O_4 + H_2SO_4 = CO_2 + CO + H_2SO_4 \cdot H_2O$$

Can also be made by passing CO_2 over red hot coke or charcoal. This last reaction is not self-sustaining but requires considerable external heat.

Chlorine.—Is readily generated from a mixture of salt, manganese dioxide and sulphuric acid.

$$(4NaCl + MnO_2 + 4H_2SO_4 = 4HNaSO_4 + 2H_2O + MnCl_2 + 2Cl.)$$

It is also readily purchased compressed in cylinders.

Cyanogen.—This is easily made by heating mercuric cyanide. It is extremely poisonous.

Ethane.—Must be made from a methyl halide, as:

$$2CH_3Cl + 2Na = 2NaCl + C_2H_6$$

Ethylene.—Is best formed by treating an ethyl halide with potassium hydroxide ($C_2H_5Br + KOH = C_2H_4 + KBr + H_2O$) or by treating ethyl alcohol with concentrated sulphuric acid.

Hydrogen.—Formed by the action of hydrochloric acid or sulphuric acid on zinc, of water on potassium or sodium, or by passing steam over red hot iron. Can also be made very economically by electrolyzing a dilute sulphuric-acid solution.

Hydrochloric Acid Gas.—Given off by the action of concentrated sulphuric acid on aqueous hydrochloric acid.

Hydrocyanic Acid Gas.—This is formed by heating sulphuric acid and sodium cyanide. It is fearfully poisonous.

Hydrogen Phosphide (Phosphine).—This is formed when phosphorus is boiled with strong potash or caustic soda, or caustic lime ($4P + 3NaOH + 3H_2O = 3H_2NaPO_2 + PH_3$). The gas as thus formed takes fire in contact with air, due to traces of P_2H_4. This compound can be removed by refrigerating mixtures and the resulting gas will not take fire spontaneously. These phosphorous compounds are very poisonous.

Hydrogen Selenide.—Formed by the action of dilute acids or aluminum selenide. This can be made by putting lump

selenium in molten aluminum. A mask and gloves should be worn when making the selenide, as the mixture occasionally spatters badly. *The utmost precaution should be observed not to breathe the seleniuretted hydrogen.*

Hydrogen Sulphide.—Readily made by treating ferrous sulphide with hydrochloric acid, by the action of sulphuric acid on low-grade mattes, or by melting paraffin and sulphur together.

Hydrogen Telluride.—Formed by the action of water on aluminum telluride. This is made by putting lumps of tellurium in molten aluminum. The slag which forms on the surface is aluminum telluride. Goggles should be worn when making this compound.

Kakodyl.—$[(CH_3)_2As]_2$. This is formed by heating arsenious anhydride and potassium acetate in a closed retort. This is ordinarily a fetid, fuming liquid, violent, poisonous, and when pure, spontaneously inflammable.

Methane.—This is most easily prepared by heating a mixture of 2 parts sodium acetate, 2 parts potassium hydroxide and 3 parts quicklime ($NaC_2H_3O_2 + KOH = CH_4 + KNaCO_3$). It can also be made by passing carbon disulphide and water vapor over red hot copper ($CS_2 + 2H_2O + 6Cu = CH_4 + 2Cu_2S + 2CuO$).

Nitric Anhydride.—Prepared by passing dry chlorine over dry silver nitrate at 95°C.

Nitrous Oxide.—Obtained by heating ammonium nitrate crystals ($NH_4NO_3 = N_2O + 2H_2O$). The reaction takes place at comparatively low temperatures.

Nitrogen.—Can be readily obtained by absorbing the oxygen from the air with phosphorus. In this case it contains about one-eightieth of its mass in argon and traces of helium, xenon, etc.

Nitrogen Peroxide.—Obtained by mixing two volumes of dry nitric oxide and one of oxygen together.

Nitric Oxide.—Obtained by the action of nitric acid on copper ($3Cu + 8HNO_3 = 3Cu(NO_3)_2 + H_2O + N_2O_2$). The gas is colorless, but oxidizes with air to nitrogen peroxide, a reddish-brown gas.

$$(4AgNO_3 + Cl_2 = 4AgCl + 2N_2O_5 + O_2)$$

Oxygen.—Is given off when manganese dioxide or potassium chlorate is heated, or, more safely, on ignition of a mixture of the two. Can also be made cheaply by electrolyzing dilute sulphuric-acid solution. Can be introduced into solution by hydrogen peroxide, sodium peroxide, fuming nitric acid, nitric acid, chloric acid, etc. The compressed gas is a common article of commerce.

Phosphine.—See hydrogen phosphide.

Sulphur Dioxide.—Formed by burning sulphur in air, or if wanted chemically pure, by the action of concentrated boiling sulphuric acid on copper ($Cu + 2H_2SO_4 = CuSO_4 + 2H_2O + SO_2$).

Sulphur Trioxide.—This is most easily formed by roasting ferric sulphate.

Principal Toxic Gases

The following list, from an address of PROF. I. GUARESCHI, before the Associazone Chim. Industr. on June 14, 1915, at Turin, is given because of the growing popularity of these compounds in warfare.

Name	Formula	Sp. gr.	Color	Discovered
Chlorine	Cl_2 [1]	2.45	Greenish yellow	Scheele 1774.
Hydrochloric acid	HCl [1]	1.26	Colorless	Priestley, 1772.
Chlorine dioxide	ClO_2 [2]	1.28	Reddish yellow	H. Davy, 1815.
Bromine	Br_2 [1]	5.6	Red	Balard, 1823.
Hydrobromic acid	HBr	......	....	....
Nitrogen dioxide	N_2O_2	1.039	Colorless	Priestley, 1772.
Nitrogen peroxide	N_2O_4 [1]	2.5	Red	Dulong, Gay-Lussac.
Nitrosyl chloride	NOCl [2]	2.33	Colorless	Gay-Lussac, 1848.
Carbonyl chloride	$COCl_2$ [2]	3.5	Colorless	J. Davy, 1812.
Carbon monoxide	CO	0.9674	Colorless	Lasonne, Priestley.
Carbon dioxide	CO_2	1.524	Colorless	V. Helmont (XVIIth).
Hydrocyanic acid	HNC [2]	0.94	Colorless	Scheele, 1782.
Cyanogen	$(CN)_2$	1.808	Colorless	Gay-Lussac, 1815.
Cyanogen chloride	CNCl [2]	2.12	Colorless	Berthollet, 1789.
Cyanogen bromide	CNBr [2]	3.60	Colorless	Serullas, 1827.
Ammonia	NH_3	0.59	Colorless	Priestley, 1775.
Sulphureted hydrogen	H_2S	1.18	Colorless	Scheele, 1777.
Sulphur dioxide	SO_2 [2]	2.247	....	....
Sulphur trioxide	SO_3 [3]	2.74	Colorless	XVth century.
Phosphine	PH_3 [3]	1.178	Colorless	Gengembre, 1785.
Arsine	AsH_3 [3]	2.69	Colorless	Scheele, 1775.

[1] Positively stated to be used in warfare.
[2] Probably being used.
[3] Possibly being used.

Fluorine Gas and Gaseous Fluorine Compounds

(All toxic)

Name	Formula	Sp. gr.	Color	Discoverer
Fluorine	F_2	1.264	Yellow	Moissan, 1886.
Hydrofluoric acid	H_2F_2	1.7	Colorless	Scheele, 1782
Boron fluoride	BF_3	......	Colorless	Gay-Lussac and Thenard, 1809.
Silicon fluoride	SiF_4	......	Colorless	Scheele, 1782.
Carbon fluoride	CF_4	3.09	Colorless	Moissan.
Fluoform	CHF_3	3.06	Colorless	Meslans.
Methyl difluoride	CH_2F_2	......	Colorless	....
Methyl fluoride	CH_3F	1.22	Colorless	Dumas and Peligot.
Phosphorus trifluoride	PF_3	3.05	Colorless	H. Davy.
Phosphorus pentafluoride	PF_5	4.5	Colorless	Thorpe.
Phosphoric oxyfluoride	POF_3	3.63	Colorless	Moissan.
Phosphorus dichlortrifluoride	PCl_2F_3	5.41	Colorless	Poulenc.
Sulphur fluoride	SF_6	5.03	Colorless	Moissan and Lebeau.
Selenium fluoride	SeF_6	......	Colorless	Prideaux, 1906.
Nitrosyl fluoride	NOF	1.68	Colorless	Gore, 1869.
Nitrile fluoride	NO_2F	2.24	Colorless	Moissan and Lebeau, 1905.
Thionyl fluoride	SOF_2	3.0	Colorless	Moissan and Lebeau, 1905.
Sulphur dioxydifluoride	SO_2F_2	3.55	Colorless	Moissan and Lebeau.
Ethyl fluoride	C_2H_5F	1.70	Colorless	Fremy.
Ethylene fluoride	$C_2H_4F_2$	......	Colorless	Chabrié.
Propyl fluoride	C_3H_7F	2.16	Colorless	Meslans, 1894
Isopropyl fluoride	C_3H_7F	2.6	Colorless	Meslans, 1894.
Isobutyl fluoride	C_4H_9F	2.58	Colorless	Moissan.
Allyl fluoride	C_3H_5F	2.07	Colorless	Meslans.
Acetyl fluoride	CH_3COF	2.16	Colorless	Meslans.
Chromyl fluoride	CrO_2F_2	......	Red	Olivieri, 1880.
Tungsten fluoride	WF_6	......	Colorless	Roscoe.
Bromine pentafluoride	BrF_5	......	Colorless	Lebeau, 1905.
Iodine pentafluoride	IF_5	......	Colorless	Moissan, 1902.

Slightly Toxic and the Rare Toxic Gases

Ozone	O_3	Carbon suboxide	(?)C_3O_2
Chlorine suboxide	Cl_2O	Nickel carbonyl	$Ni(CO)_4$
Nitrous oxide	N_2O	Diazomethane	CH_2N_2
Nitrosyl dichloride	$NOCl_2$	Ammonia	NH_3
Hydriodic acid	HI	Boron chloride	BCl_3
Stibine	SbH_3	Boron hydride	B_4H_{10}
Hydrogen silicide	SiH_4	Acetylene	C_2H_2
Formaldehyde	CH_2O	Methyl chloride	CH_3Cl
Methyl carbamine	$C \equiv NCH_3$	Methyl ether	$(CH_3)_2O$
Chromyl chloride	CrO_2Cl_2	Ethyl chloride	C_2H_5Cl
Hydrous phosphide	P_2H_4	Methyl phosphide	CH_3PH_2
Carbon oxysulphide	COS	Methyl arsenide	AsH_2CH_3
Thionyl chloride	$SOCl_2$	Dimethyl arsine	$AsH(CH_3)_2$

MINIMUM LETHAL AMOUNTS AND TOLERANCES (PER CENT.)

Gas	Rapidly fatal	Usually fatal in ½ to 1 hour	Usually endurable ½ to 1 hour	Prolonged exposure usually not harmful
HCl	....	1.5 –2.0.	0.05–1.0	0.01
Br or Cl	about 1	0.01–0.06	0.004	0.0001
SO_2	....	0.4 –0.5	0.05–0.2	0.02–0.03
HCN	about 0.3	0.12–0.15	0.05–0.06	0.02–0.04
NH_3	4–5	0.5 –1.0	0.3 –0.4	0.1
PH_3	....	0.4 –0.6	0.1 –0.2	....
H_2S	1–2	0.5 –0.7	0.2 –0.3	0.1 –0.15
CO	....	2.0 –3.0	0.5 –1.0	0.22

For use in warfare, according to Prof. Vivian B. Lewes[1] a gas should have at least twice the specific gravity of air, and should, for ease of transportation, be easily liquefiable. The principal substances which can be used in respirators to absorb the gases more commonly used in warfare are: Carbonate or bicarbonate of soda; sodium hyposulphite; potassium iodide; an alkaline iodide used with an alkaline carbonate; a mixture of alkaline carbonates and thiosulphite; hyposulphite, carbonate and glycerin.[2]

Some Properties of the Metals[3]

Brittleness or Toughness (MARTEN'S Formula).—Toughness of test length =

$$\frac{\text{ultimate strength}}{\text{yield point}} \times \frac{\text{per cent. elongation in test length.}}{100}$$

The metals then range in this order:

Pb, Pt, Fe, Al, Ni, Zn, Sn, Cu, Au, Ag.

Ductility.—Au, Ag, Pt, Fe, Ni, Cu, Al, Zn, Sn, Sb.

By some authorities aluminum is placed fourth; it has been drawn so fine that 11,400 yd. weigh only 1 oz.

Tenacity.—Steel, Ni, Fe, Cu, Al, Au, Zn, Sn, Pb.

Malleability.—Au, Ag, Al, Cu, Sn, Pt, Pb, Zn, Fe, Ni.

The thinnest metal leaf commercially attainable in 1914 was: Au, 0.000008 cm.; Al, 0.000020; Ag, 0.000021; Pt, 0.000025; Cu, 0.000034; Dutch metal, 0.00007 (KAYE and LABY).

Plasticity (MARTEN'S Formula).—Plasticity $= \frac{\text{toughness}}{\text{yield point}} \times 1000.$

MARTEN'S Classification.—Fe, Pt, Ni, Al, Zn, Cu, Ag, Au, Pb, Sn.

KURNAKOFF-SCHEMTSCHUSCHNY: K, Na, Pb, Tl, Sn, Bi, Cd, Zn, Sb.

[1] "Engineering," July 23, 1915, p. 89.
[2] "Le Genie Civil," Sept. 25, 1915, p. 205.
[3] H. O. HOFMAN, "General Metallurgy."

Elastic Constants of Solids

	Bulk modulus	Coefficient of rigidity	Young's modulus
Brass	10.0×10^{11}	3.7×10^{11}	10.4×10^{11}
Glass	4.0×10^{11}	2.4×10^{11}	6.0×10^{11}
Iron (wrought)	14.6×10^{11}	7.7×10^{11}	19.6×10^{11}
Steel	18.4×10^{11}	8.2×10^{11}	22.0×10^{11}
Aluminum	7.46×10^{11}	2.63×10^{11}	7.05×10^{11}
Bismuth, cast	3.14×10^{11}	1.20×10^{11}	3.19×10^{11}
Cadmium	4.12×10^{11}	1.92×10^{11}	4.99×10^{11}
Copper	13.1×10^{11}	4.55×10^{11}	12.3×10^{11}
Gold	16.6×10^{11}	2.80×10^{11}	8.0×10^{11}
Lead	5.0×10^{11}	0.562×10^{11}	1.62×10^{11}
Nickel	17.6×10^{11}	7.7×10^{11}	20.2×10^{11}
Palladium	17.6×10^{11}	4.04×10^{11}	11.3×10^{11}
Platinum	24.7×10^{11}	6.04×10^{11}	16.8×10^{11}
Silver	10.9×10^{11}	2.86×10^{11}	7.90×10^{11}
Tin	5.29×10^{11}	2.04×10^{11}	5.43×10^{11}
Bronze	9.52×10^{11}	2.97×10^{11}	8.08×10^{11}
Constantan	15.5×10^{11}	6.11×10^{11}	16.3×10^{11}
Manganin	12.1×10^{11}	4.65×10^{11}	12.4×10^{11}
Zinc	9.0×10^{11}	3.8×10^{11}	8.7×10^{11}
Phosphor bronze	12.0×10^{11}	4.36×10^{11}	12.0×10^{11}
German silver	....	4.5×10^{11}	11.6×10^{11}
Magnesium	4.2×10^{11}	1.7×10^{11}	....
Rhodium	28.0×10^{11}	....	....
Tantalum	18.6×10^{11}	....	....

The above values are mainly from KAYE and LABY'S, "Physical and Chemical Constants."

If the volume of a body be altered without changing its shape, the stress divided by the strain is known as the bulk modulus: $k = \frac{vp}{\Delta v}$

If a body be changed in shape without changing its volume, the modulus of elasticity is the ratio of the stress to the strain which produces it.

YOUNG'S Modulus.—The number representing the pressure or tension on a bar per unit of section divided by the compression or elongation per unit of length so produced.

Tensile Strength of Some Metals at Ordinary Temperatures

(Pounds per square inch)

Cobalt	75,000	Aluminum, cast	12,590
Nickel	54,000	Aluminum, rolled	19,290
Iron, rolled	55,000	Aluminum, hammered	22,575
Iron, cast	48,000	Aluminum, drawn	17,007
Palladium	50,000	Tellurium, cast	8,500
Platinum, wire, hard drawn	56,000	Zinc	5,000
Platinum, wire, annealed	32,000	Tin, cast	4,600
Platinum, cast	45,000	Tin, drawn	5,800
Silver, cast	41,000	Bismuth, cast	3,000
Copper, cast	24,000	Lead, cast	2,050
Copper, sheet	30,000	Lead, pipe	1,650
Copper, bolts	34,000	Lead, sheet	1,720
Copper wire, hard drawn	60,000	Antimony, cast	1,000
Copper wire, soft drawn	35,500	Tantalum	60,000
Gold, cast	20,000	Brass	50,000
Gold wire, hard drawn	37,000	German silver	66,000
Gold wire, annealed	24,000	....	....

Tensile Strengths at Low Temperatures[1]

	In kg. per sq. cm.		
	At − 252.6°C.	− 192°C.	+ 17°C.
Aluminum	4,790	5,370	2,900
Copper	6,510	4 880	3,580
Gold	....	13,400	9,860
Iron	21,700	19,700	14,700
Lead	813	581	251
Nickel	16,500	16,100	11,100
Platinum	8,600	7,250	5,080
Silver	6,400	5,390	2,780

H. O. Hofman, "General Metallurgy."
[1] F. A. and C. L. Lindemann, *Nernst's Festschrift*, 1912, p. 264.

Tensile Strength of Metals, Showing Effect of Drawing and Rolling[1]

	Lb. per sq. in.		
	Cast	Thin sheet metal	Wire
German silver	23,714–46,450	75,816–87,129	81,735–92,224
Bronze	35,960	73,380–92,086	78,049–
Brass	....	44,398–58,188	81,114–98,578
Copper	24,781	30,470–48,450	37,607–62,190
Iron (lengthwise)	....	44,331–59,484	59,246–97,908
Iron (crosswise)	....	39,838–57,350	....
Steel (lengthwise)	....	49,253–78,251	103,272–318,823
Steel (crosswise)	....	55,948–80,799	....

[1] Rearranged from tests quoted in Kent's "Mechanical Engineers' Pocket Book."

Coefficients of Linear Expansion per Degree Centigrade[1]

	0°–100°	− 190°–0°
Aluminum	0.0000233	0.000183
Antimony	0.0000168	....
Antimony (normal to axis)	0.0000089	....
Arsenic	0.000017	....
Bismuth	0.0000157	0.000013
Brass	0.000019	....
Brick	0.0000055	....
Bronze	0.0000185	....
Cadmium	0.000031	0.0000446
Cement	0.0000143	....
Cobalt	0.0000123	....
Copper	0.0000179	0.0000141
Gas-carbon	0.0000054	....
Glass	0.0000085	....
Gold	0.0000145	0.0000132

[1] The coefficient of cubic expansion is 3 times the coefficient of linear expansion.
[1] Hofman's "General Metallurgy," and" "Annuaire pour 1914, Bureau des Longitudes."

COEFFICIENT OF LINEAR EXPANSION PER DEGREE CENTIGRADE

	0°–100°	−190°–0°
Graphite	0.0000079	....
Indium	0.0000459	....
Invar (63.8 per cent. Fe, 36.2 per cent. Ni)	0.0000004	....
Iridium	0.0000067	0.0000057
Iron (cast)	0.0000122	0.0000091
Iron (wrought)	0.0000119	....
Lead	0.0000295	0.0000271
Magnesium	0.0000276	0.0000214
Marble	0.000007	....
Mercury (solid)	0.000181	....
Nickel	0.0000132	0.0000101
Osmium	0.0000068	....
Palladium	0.0000119	0.0000120
Platinum	0.0000090	0.0000088
Potassium	0.000083	....
Rhodium	0.0000086	....
Ruthenium	0.0000099	....
Selenium (40°)	0.000037	....
Silver	0.0000195	....
Sodium	0.000072	....
Steel	0.000011	....
Steel (hardened)	0.0000136	....
Tellurium	0.000017	....
Thallium	0.000031	....
Tin	0.0000227	0.0000226
Zinc	0.0000294	0.0000264
Aluminum bronze	0.000017	....
Brass (Cu 66, Zn 34)	0.0000189	....
Bronze (Cu 32, Zn 2, Sn 5)	0.0000177	....
Constantan (Cu 60, Ni 40)	0.000017	....
German silver (Cu 60, Ni 15, Zn 25)	0.0000184	....
Magnalium (Al 86, Mg 13)	0.000024	....
Phosphor bronze (Cu 97.6, 2Sn, P 0.2)	0.0000168	....
Platinum-iridium (Ir 10 per cent.)	0.0000087	....
Solder (Pb 2 : Sn 1)	0.000025	....
Speculum metal (Cu 68, Sn 32)	0.0000193	....
Cement and concrete	0.000010–14	....
Glass, soft $68SiO_2$, $14Na_2O$, $7CaO$	0.0000085	....
Glass, flint $45SiO_2$, $8K_2O$, $46PbO$	0.0000078	....
Granite	0.0000083	....
Ice (−10° to 0°)	0.0000507	....
Masonry	0.000004–7	....
Silica, fused (−80° to 0°)	0.00000022	....
(0° to 30°)	0.00000042	....
(0° to 100°)	0.00000050	....
(0° to 1000°)	0.00000054	....
Sandstone	0.000007–12	....
Slate	0.000006–10	....

Cubic Expansion of Gases, per Degree Centigrade[1]

	Constant volume	Constant pressure
Air	0.0036650	0.003676
Carbon monoxide	0.0036667	0.0036688
Carbon dioxide	0.003688	0.00371
Cyanogen	0.003829	0.003877
Hydrogen	0.0036678	0.0036613
Nitrogen	0.0036682	0.003670
Oxygen	0.0036741	0.00486
Nitrous oxide	0.003676	0.0037195
Ammonia	....	0.003854
Sulphur dioxide	0.0038453	0.0039028
Argon	0.003668	....
Helium	0.0036627	....

Cubic Expansion of Liquids

Mercury (0°–100°C.)	0.0001818
Water	see p. 174
Burning oils of sp. gr. 0.795–0.825	0.00072
Benzine	0.00081
Light lubricating oil	0.00068
Heavy lubricating oil	0.00063
Sodium (liquid)	0.000226

Hardness

"The customary hardness test at the present time is that of Brinnell, which consists in making on a flat surface of the material an indentation by means of a small steel ball applied under known pressure. According to Rosenhain perhaps the best definition of hardness is "the power of resisting local displacement of portions of its surface." But it is at once evident that this power is by no means a simple and definite property of the material which will reproduce itself in all circumstances. Thus the displacement of a portion of the substance of a material may occur by plastic flow—the material may be indented at one point while its level is raised at other points; in other circumstances or in other materials the displacement may occur by direct fracture, as in the scratching of a brittle material. Either of these forms of local displacement may be brought about by the application of a steadily increasing force or by a rapidly applied force, *i.e.*, by a shock or blow. It is by no means certain that the power of resisting all these various forms of displacement will be identical or even proportional, so that the material which displays the highest scratch hardness is not necessarily the hardest under an indentation test. Where hardness is referred to, therefore, the manner of measuring it should always be specified.

[1] From "Annuaire pour 1914, Bureau des Longitudes," with a few values from other sources.

Scale of Hardness (Mohs)

Agate	7.0	Gypsum	2.0[1]
Alabaster	1.7	Heavy spar	3.3
Alum	2.0–2.5	Hornblende	5.5
Amber	2.0–2.5	Iridium	6.0
Andalusite	7.5	Jasper	7.0
Anthracite	2.2	Kaolin	1.0
Antimony	3.3	Lead	1.5
Apatite	5.0[1]	Meerschaum	2.0–3.0
Aragonite	3.5	Mica	2.5–3.0
Arsenic	3.5	Nickel	5.0–5.5
Asphalt	1.0–2.0	Onyx	7.0
Augite	6.0	Opal	4.0–6.0
Beryl	7.8	Palladium	4.8
Bismuth	2.5	Platinum	4.3
Calamine	5.0	Quartz	7.0[1]
Calcite	3.0[1]	Ruby	9.0
Copper	2.5–3.0	Saltpeter	2.0
Copperas	2.0	Sapphire	9.0[1]
Copper sulphate	2.5	Serpentine	3.0–4.0
Corundum	9.0	Silver	2.5–3.0
Diamond	10.0[1]	Spinel	8.0
Dolomite	3.5–4.0	Stibnite	2.0
Emery	9.0	Sulphur	1.5–2.5
Feldspar	6.0[1]	Talc	1.0
Fluorite	4.0[1]	Topaz	8.0[1]
Gold	2.5–3.0	Tin	2.0–3.0
Granite	7.0	Zinc	4.0
Graphite	0.5–1.0		

"Among the various methods which have been proposed for the measurement of hardness, it seems probable that the Brinnell ball-test, measuring indentation hardness, is probably that one which most nearly approaches our fundamental ideal of constituting a measure of a single definite property. In this case the test probably measures a group of properties of a fairly simple type. That this is the case may be inferred from the fact that tests with balls of different diameter can be rendered fairly comparable."

$$\text{Hardness} = \frac{\text{load in kg.}}{\text{area of concavity of indentation}} \times \sqrt[5]{\text{radius of ball}}$$

The Brinnell hardness number is nearly proportional to the ultimate stress determined by tensile tests. On the other hand, ball-hardness number is not a safe guide as to the power to resist abrasion.[2] A better test for resistance to wear is

[1]The materials marked thus ([1]) are the standards on this scale. The hardness is determined by scratching an unknown with these standards. One can scarcely determine within half a point what the hardness is. The finger nail may be assumed at about 2.5, and a knife blade at 6.5.

[2] Rosenhain's "Introduction to Physical Metallurgy."

y that of the DERIHON machine, in which the edge of a
el disc revolving in oil is pressed against the test speci-
Some comparative BRINNELL numbers and resistances
are given below.

BOTTONE'S SCALE OF HARDNESS[2]

...	3010	Copper......	1360	Iridium.....	984	Tin.........	651
se.	1456	Palladium...	1200	Gold........	979	Lead........	570
..	1450	Platinum....	1107	Aluminum....	821	Thallium....	565
..	1410	Zinc........	1077	Cadmium...	760	Calcium.....	405
..	1375	Silver......	990	Magnesium .	726	Sodium.....	400
..	....	....	....	....	....	Potassium...	230

BRINNELL HARDNESS NUMBERS[3]

	Cooled in	500 kg. (*a*)	3000 kg. (*b*)	Resistance to wear
bronze:				
ent. Sn...............	Lime	86	107	93–100
ent. Sn...............	Sand	158	196	143–158
ent. Sn, 10 per cent. Pb.	Lime	80	103	80–89
ent. Sn, 10 per cent. Pb.	Sand	50	69	65–70
l:				
ent. Sn, 2 per cent. Zn..	Sand	70	82	65–74
ent. Sn, 2 per cent. Zn..	Lime	86	107	86–93
e bronze............	Sand	109	137	109–119
	Bronze	119	143	124–130

mm. ball, applied under 500 kg. pressure 15 seconds.
nm. ball, applied under 3000 kg. pressure 30 seconds.

LATENT HEAT OF EVAPORATION[4]

....	51.0	Magnesium...............	1315.0
1.............	2227.0	Nitric anhydride (N_2O_5)....	44.81
ublimation)....	60.0	Nitrous oxide (N_2O)........	100.6
(calculated)...	359.0	Nitric acid................	115.08
ic.............	121.0	Oxygen....................	50.9
....	120.7	Phosphorus................	287.0
thyl...........	208.92	Potassium.................	592.0
....	263.86	Selenium..................	140.0
(liquid NH_3)...	341.0	Silicon (calculated).........	1262.0
loride.........	53.0	Silver.....................	715.0
....	45.6	Sodium....................	1015.0
....	398.0	Sulphur...................	72.0
oxide..........	49.32	Sulphur dioxide............	94.56
sulphide.......	86.67	Sulphuric acid.............	122.1
alculated)......	38.37	Sulphuric anhydride........	147.5
....	61.9	Stannic chloride...........	30.53
....	123.0	Tin.......................	271.0
....	24.0	Water.....................	538.0
alculated).....	2.54	Zinc......................	425.0
....	68.0		

Fifth Congress, Int. Assoc. for Testing Materials."
our. Sci., 1874, Vol. 150, p. 644.
t et Alliages, p. 8, 1915.
of these values are from J. W. RICHARDS, "Metallurgical Calcula-
few from CREMER and BICKNELL'S "Chemical and Metallurgical
.."

Latent Heats of Fusion[1]

Aluminum	100.0	Mercury	2.83
Antimony[2]	40.2[2]	Nickel	68.0
Bismuth	12.64	Palladium	36.3
Bromine	16.18	Platinum	27.18
Cadmium	13.02	Phosphorus	5.13
Calcium	52.6	Potassium	16.0
Copper	43.3	Potassium nitrate	47.37
Cobalt	68.0	Selenium	13.0
Gallium	19.11	Silicon	127.7
Gold	16.3	Silver	23.5
Ice	79.77	Steel	20.0
Iodine	11.7	Sodium	31.7
Iridium	26.1	Sulphur	9.37
Iron—cast-white	23.0	Thallium	5.8
Iron—cast-gray	33.0	Tellurium	19.0
Iron—pure	69.0	Tin	14.0
Lead	5.37	Water	79.76
Magnesium	58.0	Zinc	22.6

Latent Heats of Fusion—Compounds[3]

Oxides		
Alumina	Al_2O_3	50.9
Silica	SiO_2	76.1
Titanium oxide	TiO_2	35.8
Halides		
Arsenic chloride	$AsCl_3$	69.74
Lead bromide	$PbBr_2$	12.34
Lead chloride	$PbCl_2$	20.90
Manganese chloride	$MnCl_2$	49.37
Stannic chloride	$SnCl_4$	46.84
Nitrates		
Potassium nitrate	KNO_3	48.90
Sodium nitrate	$NaNO_3$	64.87
Silicates		
Al-calcium silicate (anorthite)	$CaAl_2Si_2O_8$	100
Al-potassium silicate (orthoclase)	$KAlSi_3O_8$	100
Al-potassium silicate (microcline)	$KAlSi_3O_8$	83
Calcium silicate (wollastonite)	$CaSiO_3$	100
Ca-magnesium silicate (malacolite)	$Ca_3MgSi_4O_{12}$	94
Ca-magnesium silicate (diopside)	$CaMgSi_2O_6$	100
Magnesium silicate (enstatite)	$MgSiO_3$	125
Magnesium silicate (olivine)	Mg_2SiO_4	130
Iron silicate (fayalite)	Fe_2SiO_4	85

[1] Most of these values are from J. W. Richard's "Metallurgical Calculations," a few from Cremer and Bicknell's "Chemical and Metallurgical Handbook."
[2] This is an experimental value. Theory points to a value of about 16.
[3] J. W. Richards, "Metallurgical Calculations."

Sulphides

Lead sulphide	PbS	104

Specific Heats of Non-metals and Alloys[1]

Material	Specific heat	Material	Specific heat
Solids:		Liquids:	
Asbestos (20°–100°)	0.20	Alcohol, ethyl (40°)	0.65
Brass (red)	0.09	Alcohol methyl (12°)	0.60
Brass (yellow)	0.088	Benzene, C_6H_6 (10°)	0.340
Brickwork	About 0.2	Benzine	0.45
Carbon, graphite	0.16	Benzol, (19°–30°)	0.4158
Clay	0.19	Gasoline	0.53
Coal	0.24	Glycerine (18°–50°)	0.58
Fluorspar (30°)	0.21	Hydrochloric ($HCl + 10H_2O$) (18°)	0.749
German silver (0°–100°)	0.095		
Glass, crown (10°–50°)	0.16–0.20	Hydrogen (253°)	6.00
Glass, flint (10°–50°)	0.12	Kerosene	0.47
Granite (20°–100°)	0.19–0.20	Lead (molten)	0.03
Ice	0.502	Mercury (5°–36°)	0.0333
Iron, pure	0.116	Nitric ($HNO_3 + 10H_2O$) (18°)	0.768
Iron, cast	0.13	Nitrogen (−208° to −196°)	0.43
Iron, wrought	0.11	Oil, olive (7°)	0.47
Marble (18°)	0.21	Oxygen (−200° to −183°)	0.35
Quartz (0°)	0.174	Sea water (17°)	0.94
Quartz (350°)	0.279	Sulphur (119°–147°)	0.2346
Sand (20°–100°)	0.19	Sulphuric (H_2SO_4) (16°–20°)	0.3315
Steel	0.12	Sulphuric ($H_2SO_4 + 5H_2O$) (16°–20°)	0.5764
Stone	About 0.2		
Wood	0.45–0.65	Turpentine (18°)	0.42

The specific heat of a substance is the number of B.t.u.'s required to raise the temperature of a pound of the substance 1°F. or of 1 kg. of water 1°C. There is much discordant data on the subject and several tables are given. The user is advised to look over all of the tables, as the data is given in several forms.

Specific Heats of Some Metals[2]

Metal	Specific heat, At about 15°C.	Specific heat, At about melting point	As a gas	Metal	Specific heat, At about 15°C.	Specific heat, At about melting point	As a gas
Ag	0.055	0.076	0.046	Mn	0.122	......	......
Al	0.167	0.308	0.1852	Mo	0.066	......	......
Bi	0.030	0.030	......	Na	0.293	......	0.2174
Cb	0.068	......	......	Ni	0.109	0.161	......
Cd	0.054	0.062	0.0446	Os	0.031	......	......
Co	0.106	0.204	......	P	......	......	0.064
Cu	0.086	0.118	......	Pb	0.030	0.034	......
Fe	0.116	0.162	......	Pt	0.032	0.046	......
Hg	0.033	0.032	0.025	Sr	0.0735	......	......
Ir	0.030	0.040	......	Sb	0.048	0.054	0.416
K	0.166	0.23	0.128	Si	......	......	0.107
Li	0.941	0.975	0.714	Sn	0.055	0.059	0.424
Mg	0.246	......	0.2084	Tl	0.03355	......	0.024
				Zn	0.093	0.122	0.076

[1] From Pierce and Carver's, "Formulas and Tables for Engineers," with some additions from other authorities. For the elements, see the table on page 196.

[2] The first two columns are from Hofman's "General Metallurgy," the values for the gaseous state are from J. W. Richards "Metallurgical Calculations."

Specific Heats of the Elements[1]

A table compiled from various sources.

Substance[1]	Temperature[1]	Sp. heat[1]	Substance[1]	Temperature[1]	Sp. heat[1]
Aluminum	−182°–15°	0.168	Lead........	300°	0.0338
	17°–100°	0.217		Molten	0.0402
	600°	0.282	Lithium.....	0°–19°	0.837
Antimony.....	−186°– −79°	0.0462		0°–100°	1.093
	1°–20°	0.0503	Magnesium..	−186°– −79°	0.189
	Molten			17°–100°	0.248
	632°–830°	0.0603		225°	0.281
Arsenic: Cryst	0°–100°	0.0822	Manganese..	−188°–20°	0.093
Amorph......	21°–65°	0.076		14°–97°	0.189
Barium........	−185°–20°	0.068	Mercury.....	−213°	0.0266
	0°–100°	0.05		0°–80°	0.0331
Beryllium.....	0°–100°	0.425	Molybdenum	−185°–20°	0.063
Bismuth.......	−186°	0.0284		15°–91°	0.072
	22°–100°	0.0304	Nickel.......	− 186°–18°	0.086
	Molten	0.0363		18°–100°	0.109
Bromine: Solid	− 78°– −20°	0.084	Nitrogen, liq.	−208°– −196°	0.43
Liquid.......	13°–45°	0.107	Osmium.....	19°–98°	0.031
Gas..........	150°–230°	0.0570	Palladium ...	18°–100°	0.059
Boron, amorph.	0°–100°	0.307	Phosphorus:		
Cadmium......	−186°– −79°	0.050	Yellow	− 78°–10°	0.17
	Pure 18°–99°	0.055	Yellow	13°–36°	0.202
Cæsium.	0°–26°	0.048	Liquid	49°–98°	0.205
Calcium.......	0°–100°	0.1704	Red	15°–98°	0.17
Carbon........	0°–20°	0.145	Platinum	−186°–18°	0.0293
Gas carbon...	24°–68°	0.204		18°–100°	0.0324
Charcoal.....	0°–24°	0.165		1230°	0.0461
Charcoal.....	0°–224°	0.238	Potassium ...	− 78°–23°	0.166
Graphite.....	− 50°	0.114	Rhodium	10°–97°	0.058
Graphite.....	11°	0.160	Ruthemium .	0°–100°	0.061
Graphite.....	202°	0.297	Selenium:		
Graphite.....	977°	0.467	Cryst......	22°–62°	0.084
Diamond.....	11°	0.113	Amorph....	18°–38°	0.095
Cerium........	0°–100°	0.045	Silicon, cryst.	−185°–20°	0.123
Chlorine, liquid	0°–24°	0.226		57°	0.183
Chromium.....	−200°	0.067		232°	0.203
	0°	0.104	Silver	−186°– −79°	0.496
	17°–100°	0.110		15°–100°	0.056
	400°	0.133		427°	0.059
Cobalt........	−182°–15°	0.082	Sodium: Solid	−185°–20°	0.234
	15°–100°	0.103	Solid	10°	0.297
	15°–630°	0.123	Liquid	128°	0.333
Copper	−192°–20°	0.0798	Sulphur:		
	20°–100°	0.0936	Rhombic ...	17°–45°	0.163
	900°	0.118	Liquid......	119°–147°	0.235
	Molten	0.1318	Tantalum....	−185°–20°	0.033
Didymium	0°–100°	0.046		58°	0.036
Gallium, solid .	12°–23°	0.079	Tellurium....	15°–100°	0.0483
Liquid	12°–119°	0.080	Thallium....	−192°–20°	0.0300
Germanium ...	0°–100°	0.074		17°–100°	0.0335
Gold	−185°–20°	0.035	Thorium	0°–100°	0.028
	18°–990°	0.0303	Tin.........	−186– −79°	0.0486
	Molten	0.0358		19°–99°	0.0552
Indium	0°–100°	0.057		Molten	
Iodine	9°–98°	0.054		240°	0.064
	Vapor	0.03489	Titanium....	−185°–20°	0.082
Iridium	−186°–18°	0.0282		0°–100°	0.113
	18°–100°	0.0323		0°–440°	0.162
Iron	−192°–20°	0.089	Tungsten....	−185°–20°	0.036
	20°–100°	0.119		20°–100°	0.034
	225°	0.137	Uranium.....	0°–98°	0.028
	0°–1100°	0.153	Vanadium...	0°–100°	0.115
	Molten	0.25	Zinc.........	−233°	0.0268
Lanthanum ...	0°–100°	0.045		−192°–20°	0.084
Lead..........	−253°	0.120		20°–100°	0.093
	−192°–20°	0.0293		300°	0.104
	15°–100°	0.0309	Zirconium....	0°–100°	0.068

[1] See also the table on p. 195.

Specific Heats of Metals for $t°$ Centigrade[1]

Aluminum	$0.2220 + 0.00005t$
Antimony	$0.04864 + 0.0000084t$
Beryllium	$0.3756 + 0.00106t$
Boron	$0.22 + 0.00035t$
Carbon (under 250°)	$0.1567 + 0.00036t$
Carbon (250°–1000°)	$0.2142 + 0.000166t$
Carbon (above 1,000°)	$0.5 - (120 \div t)$
Nickel (up to 230°)	$0.10836 + 0.00002233t$
Potassium	$0.1858 + 0.00008t$
Silicon	$0.17 + 0.00009t$
Sodium	$0.2932 + 0.00019t$
Titanium	$0.978 + 0.000147t$
Zinc	$0.0906 + 0.000044t$
Bismuth	$0.0285 + 0.00002t$
Bromine	$0.105 + 0.0011t$
Copper	$0.0939 + 0.00001778t$
Cadmium	$0.0546 + 0.000012t$
Iridium	$0.0317 + 0.000006t$
Lead	$0.02925 + 0.000019t$
Palladium	$0.0582 + 0.00001t$
Platinum	$0.0317 + 0.000006t$
Silver (to 400°)	$0.555 + 0.00000943t$
Silver (over 400°)	$0.5758 + 0.0000044t + 0.000000006t^2$
Tin	$0.0560 + 0.000044t$

Specific Heats of Chlorides

Chlorides	Formula	Range	Specific heat
Ammonium chloride	NH_4Cl	23°–100°	0.3908
Arsenious chloride	$AsCl_3$(solid)	14°–98.3°	0.0896
	$AsCl_3$(gas)	159°–268°	0.1122
Barium chloride	$BaCl_2$	14°–98°	0.0896
Calcium chloride	$CaCl_2$	23°–99°	0.1730
Chromium chloride	$CrCl_2$	....	0.1430
Cuprous chloride	Cu_2Cl_2	17°–98°	0.1383
Lead chloride	$PbCl_2$	20°–100°	0.0651
		160°–380°	0.707
Lithium chloride	LiCl	13°–97°	0.2821
Magnesium chloride	$MgCl_2$	24°–100°	0.1946
Manganese chloride	$MnCl_2$	....	0.1425
Mercurous chloride	HgCl	7°–99°	0.0521
Mercuric chloride	$HgCl_2$	13°–98°	0.0689
Potassium chloride	KCl	14°–99°	0.1730
Silver chloride	AgCl	160°–380°	0.0978
Sodium chloride	NaCl	15°–98°	0.2140
Strontium chloride	$SrCl_2$	13°–98°	0.1199
Titanium chloride	$TiCl_4$ (solid)	13°–99°	0.1881
	$TiCl_4$ (gas)	163°–271°	0.1290
Tin (ous)	$SnCl_2$	20°–99°	0.1016
(ic)	$SnCl_4$ (solid)	14°–98°	0.1476
	$SnCl_4$ (gas)	149°–273°	0.0939
Zinc chloride	$ZnCl_2$.	21°–99°	0.1362

[1] J. W. Richards, "Metallurgical Calculations."
[2] From Hofman's, "General Metallurgy."

Specific Heats of the Oxides[1]

Oxide	Formula	Range	Specific heat
Beryllium oxide	Be_2O_3	0°–100°	0.2471
Boron oxide	B_2O_3	16°–98°	0.2374
Antimonious oxide	Sb_2O_3	18°–100°	0.0927
Alumina	Al_2O_3	0°–1200°	0.2081+ 0.0000876t
Alumina	Al_2O_3	above 2200°	0.5935
Arsenious oxide	As_2O_3	13°–97°	0.1276
Calcium oxide	CaO	0°–t°	0.1715+ 0.00007t
Chromium oxide	Cr_2O_3	10°–99°	0.1796
Ferric oxide	Fe_2O_3	0°–t°	0.1456+ 0.000188t
Ferroso-ferric oxide	Fe_3O_4	0°–t°	0.1447+ 0.000188t
Magnesium oxide	MgO	24°–100°	0.2440
Magnesium hydrate	$Mg(OH)_2$	19°–50°	0.312
Manganese oxide	MnO	13°–98°	0.157
Manganese sesquioxide	Mn_2O^3	15°–99°	0.162
Manganese sesquioxide, hydrated	$Mn_2O^3.H_2O$	21°–52°	0.1760
Manganese peroxide	MnO_2	17°–48°	0.1590
Nickel oxide	NiO	13°–98°	0.1588
Silica	SiO_2	0°–1200°	0.1833+ 0.000077t
Mercuric oxide	HgO	5°–98°	0.0518
Molybdic oxide	MoO_3	21°–52°	0.1540
Lead oxide	PbO	22°–98°	0.0512
Bismuth oxide	Bi_2O_3	20°–98°	0.0605
Thoric oxide	Th_2O_3	0°–100	0.0548
Tin oxide	SnO_2	16°–98°	0.0936
Titanic oxide	TiO_2	0°–200°	0.1790
Tungstic oxide	WO_3	8°–98°	0.0798
Zirconium oxide	ZrO_2	0°–100°	0.1076
Zinc oxide	ZnO	0°–1000°	0.1212+ 0.0000315t
Cuprous oxide	Cu_2O	19°–51°	0.1110
Cupric oxide	CuO	12°–98°	0.1420
Columbic oxide	Cb_2O_5	0°–t°	0.1037+ 0.00007t
Ferrous oxide	FeO	....	0.1460(a)
Potassium oxide	K_2O	....	0.1390(a)
Sodium oxide	Na_2O	....	0.2250(a)
Lithium oxide	Li_2O	....	0.4430(a)

(a) Theoretical results, according to Vogt.

Specific Heats of Sulphates

Sulphates	Formula	Range	Specific heat
Barium sulphate	$BaSO_4$	10°–98°	0.1128
Calcium sulphate	$CaSO_4$	13°–98°	0.1965
Copper sulphate	$CuSO_4$	23°-100°	0.1840
Lead sulphate	$PbSO_4$	20°–99°	0.0827
Magnesium sulphate	$MgSO_4$	25°–100°	0.2250
Manganese sulphate	$MnSO_4$	21°–100°	0.1820
Nickel sulphate	$NiSO_4$	15°–100°	0.2160
Potassium acid sulphate	$HKSO_4$	19°–51°	0.2440
Potassium sulphate	....	15°–98°	0.1901
Sodium sulphate	....	17°–98°	0.2312
Strontium sulphate	....	22°–99°	0.1428
Zinc sulphate	....	22°–100°	0.1740

[1] J. W. Richards, "Metallurgical Calculations," Vol. II.

Specific Heats of Nitrates

Nitrates	Formula	Range	Specific heat
ım nitrate............	NH_4NO_3	14°–31°	0.4550
ıitrate................	$Ba(NO_3)_2$	13°–98°	0.1523
ate...................	$Pb(NO_3)_2$	17°–100°	0.1173
n nitrate..............	KNO_3	13°–98°	0.2387
rate..................	$AgNO_3$	16°–99°	0.1435
ıitrate................	$NaNO_3$	14°–98°	0.2782
n nitrate..............	$Sr(NO_3)_2$	17°–47°	0.1810
otassium nitrate.......	$KNa(NO_3)_2$	15°–100°	0.2350
ıitrate (fused)..........	$NaNO_3$(liquid)	320°–430°	0.4130
n nitrate (fused).......	KNO_3 (liquid)	350°–435°	0.3319

Specific Heats of Carbonates

Carbonates	Formula	Range	Specific heat
arbonate.............	$BaCO_3$	11°–99°	0.1104
carb. (calcite)..........	$CaCO_3$	20°–100°	0.2086
carb. (aragonite)	$CaCO_3$	18°–99°	0.2085
carb. (marble)..........	$CaCO_3$	23°–98°	0.2099
magnesium (dolomite)..	....	20°–100°	0.2179
erite)	$FeCO_3$	9°–98°	0.1935
nesium................	$Mg_7Fe_2(CO_3)_9$	20°–100°	0.2270
ussite)	$PbCO_3$	16°–47°	0.0791
n carbonate...........	K_2CO_3	23°–99°	0.2162
arbonate.............	Na_2CO_3	16°–98°	0.2728
n carbonate...........	$SrCO_3$	8°–98°	0.1475

Specific Heats of Chromates

Chromates	Formula	Range	Specific heat
omate.................	$PbCrO_4$	19°–50°	0.0900
mate..................	$FeCrO_4$	19°–50°	0.1590
n bichromate..........	$K_2Cr_2O_7$	16°–98°	0.1894
n chromate...........	K_2CrO_4	19°–98°	0.1851

Specific Heats of Borates

Borates	Formula	Range	Specific heat
orate..................	PbB_2O_4	15°–98°	0.905
aborate...............	PbB_4O_7	18°–99°	0.2198
n biborate............	$K_2B_2O_4$	16°–98°	0.2048
n tetraborate..........	$K_2B_2O_7$	18°–99°	0.2198

Specific Heats of Bromides, Iodides and Fluorides

Bromides	Formula	Range	Specific heat
Lead bromide	$PbBr_2$	16°–98°	0.0532
		190°–430°	0.0532
Potassium bromide	KBr	16°–98°	0.1132
Silver bromide	AgBr	15°–98°	0.0739
Sodium bromide	NaBr	....	0.1384
Cuprous iodide	CuI	20°–99°	0.0819
Lead iodide	PbI_2	14°–98°	0.0427
Mercurous iodide	HgI	17°–99°	0.0395
Mercuric iodide	HgI_2	18°–99°	0.0420
Potassium iodide	KI	20°–99°	0.0819
Silver iodide	AgI	15°–264°	0.577
Sodium iodide	NaI	16°–99°	0.0868
Clacium fluoride	CaF_2	15°–99°	0.2154
Sodium-aluminum fluoride	Na_3AlF_6	16°–99°	0.2522

Specific Heats of Phosphates

Phosphates	Formula	Range	Specific heat
Calcium acid phosphate	CaP_2O_6	15°–98°	0.1992
Calcium phospo-fluoride (apatite)	$3Ca_3P_2O_8 \cdot CaF_2$	15°–99°	0.1903
Lead, tribasic diphosphate	$Pb_3P_2O_8$	11°–98°	0.0798
Lead pyrophosphate	$Pb_2P_2O_7$	11°–98°	0.821
Potassium pyrophosphate	$K_4P_2O_7$	17°–98°	0.1901
Silver phosphate	Ag_3PO_4	19°–50°	0.0898
Sodium pyrophosphate	$Na_4P_2O_7$	17°–98°	0.2283

Specific Heats of Aluminates, Titanates, Etc.

Aluminates	Formula	Range	Specific heat
Spinel	$MgAl_2O_4$	15°–47°	0.1940
Chrysoberyl	$BeAl_2O_4$	0°–100°	0.2004
Ilmenite	$FeTiO_3$	15°–50°	0.177
Wulfenite	$PbMoO_4$	15°–50°	0.083
Scheelite	$CaWO_4$	15°–50°	0.097
Wolframite	$Fe(Mn)WO_4$	15°–50°	0.098
Potassium permanganate	$KMnO_4$	15°–15°	0.179
Potassiun chlorate	$KClO_3$	10°–100°	0.210
Glass	Ca,K,SiO_3	14°–99°	0.1977
Glass, flint	....	10°–50°	0.177
Glass, crown	....	10°–50°	0.161

Compound Sulphides

Sulphides	Formula	Range	Specific heat
Bornite	Cu_3FeS_3	10°–100°	0.1177
Bournonite	$PbCuSbS_3$	10°–100°	0.0730
Cobaltite	CoAsS	15°–99°	0.0991
Chalcopyrite	$CuFeS_2$	14°–98°	0.1310
Mispickel	FeAsS	10°–100°	0.1030
Proustite	Ag_3AsS_3	10°–100°	0.0807
Pyrargyrite	Ag_3SbS_3	10°–100°	0.0757
Tetrahedrite	$Cu_4Sb_2S_7$	10°–100°	0.0987

Specific Heats of Sulphides

Sulphides	Formula	Range	Specific heat
Antimony sulphide	Sb_2S_3	23°–99°	0.0840
Arsenic sulphide	AsS	20°–100°	0.1111
Arsenic sulphide	As_2S_3	20°–100°	0.1132
Bismuth sulphide	Bi_2S_3	11°–99°	0.0600
Cobalt sulphide	CoS	15°–98°	0.1251
Copper sulphide	Cu_2S	9°–97°	0.1212
	Cu_2S	0°–t°	$0.1126 + 0.00009t$
Ferrous sulphide	FeS	17°–98°	0.1357
Iron sulphide	Fe_7S_8	20°–100°	0.1602
Iron pyrites	FeS_2	19°–98°	0.1301
Lead sulphide	PbS	16°–98°	0.0509
Manganese sulphide	MnS	10°–100°	0.1392
Mercury sulphide	HgS	14°–98°	0.0512
Molybdenum sulphide	MoS_2	20°–100°	0.1233
Nickel sulphide	NiS	15°–98°	0.1281
Silver sulphide	Ag_2S	7°–98°	0.0746
	Ag_2S	0°–t°	$0.0685 + 0.00005t$
Zinc sulphide	ZnS	15°–98°	0.1230
Stannous sulphide	SnS	13°–98°	0.0837
Stannic sulphide	SnS_2	12°–95°	0.1193

Specific Heats of Arsenides and Antimonides

Antimonides	Formula	Range	Specific heat
Domeykite	Cu_3As	10°–100°	0.0949
Dyscrasite	Ag_3Sb	10°–100°	0.0558
Löllingite	$FeAs_2$	10°–100°	0.0864
Smaltite	$CoAs_2$	10°–100°	0.0830

Specific Heats of Silicates

Silicates	Formula	Range	Specific heat
Aluminum silicate (topaz)	$Al_2Si(F)O_5$	12°–100°	0.1997
Al-calcium silicate (anorthite)	$CaAl_2Si_2O_8$	0°–100°	0.189
	$CaAl_2Si_2O_8$	0°–1200°	0.294
Al-beryllium silicate (beryl)	$BeAl_2Si_2O_8$	12°–100°	0.2066
Al-potassium silicate (microcline)	$KAlSi_3O_8$	20°–100°	0.197
Al-potassium silicate (orthoclase)	$KAlSi_3O_8$	20°–100°	0.1877
Calcium silicate (wollastonite)	$CaSiO_3$	0°–100°	0.179
	$CaSiO_3$	0°–1200°	0.288
Ca-magnesium silicate (diopside)	$CaMgSi_2O_6$	0°–100°	0.194
	$CaMgSi_2O_6$	0°–1200°	0.281
Ca-magnesium silicate (malacolite)	$Ca_3MgSi_4O_{12}$	0°–100°	0.186
	$Ca_3MgSi_4O_{12}$	0°–1200°	0.264
Iron silicate (fayalite)	Fe_2SiO_4	0°–100°	0.170
Iron-aluminum (garnet)	$Fe_3Al_2Si_3O_{12}$	16°–100°	0.1758
Magnesium silicate (enstatite)	$MgSiO_3$	0°–100°	0.206
	$MgSiO_3$	0°–1200°	0.301
Magnesium silicate (olivine)	Mg_2SiO_4	0°–100°	0.2200
Zirconium silicate (zircon)	$ZrSiO_4$	15°–100°	0.1456
Basalt		20°–470°	0.1990
Bessemer slag		14°–99°	0.1691
Granite		20°–524°	0.2290

Specific Heat of Water[1]

(Defining specific heat at 0° to 1°C. as unity)

Temperature, deg. F.	Specific heat	Temperature, deg. F.	Specific heat	Temperature, deg. F.	Specific heat
32	1.0000	176	1.0089	320	1.0294
50	1.0005	194	1.0109	338	1.0328
68	1.0012	212	1.0130	356	1.0364
86	1.0020	230	1.0153	374	1.0407
104	1.0030	248	1.0177	392	1.0440
122	1.0042	266	1.0204	410	1.0481
140	1.0056	284	1.0232	428	1.0524
158	1.0072	302	1.0262	446	1.0568

Specific Heat of Water

(Defining specific heat at 16° to 17° as unity)

Temperature, deg. C.	Specific heat	Thermal capacity, $0° - t°$	Temperature, deg. C.	Specific heat	Thermal capacity, $0° - t°$
0	1.00940	0.00000	25	0.99806	25.05131
1	1.00855	1.00898	26	0.99795	26.04932
2	1.00770	2.01710	27	0.99784	27.04720
3	1.00690	3.02440	28	0.99774	28.04499
4	1.00610	4.03090	29	0.99766	29.04269
5	1.00530	5.03660	30	0.99759	30.04031
6	1.00450	6.04150	31	0.99752	31.03786
7	1.00390	7.04570	32	0.99747	32.03536
8	1.00330	8.04930	33	0.99742	33.03280
9	1.00276	9.05233	34	0.99738	34.03020
10	1.00230	10.05486	35	0.99735	35.02757
11	1.00185	11.05694	36	0.99733	36.02491
12	1.00143	12.05858	37	0.99732	37.02224
13	1.00100	13.05980	38	0.99732	38.01956
14	1.00064	14.06062	39	0.99733	39.01689
15	1.00030	15.06109	40	0.99735	40.01422
16	1.00000	16.06124	41	0.99738	41.01159
17	0.99970	17.06109	42	0.99743	42.00899
18	0.99941	18.06064	43	0.99748	43.00644
19	0.99918	19.05994	44	0.99753	44.00395
20	0.99895	20.05900	45	0.99760	45.00152
21	0.99872	21.05783	46	0.99767	45.99916
22	0.99853	22.05645	47	0.99774	46.99686
23	0.99836	23.05490	48	0.99781	47.99464
24	0.99820	24.05318	49	0.99790	48.99250
25	0.99806	25.05131	50	0.99800	49.99045

[1] From "The Petroleum Year Book, 1914."

Mean Specific Heats of Gases

	Under constant pressure	Under constant volume	γ
Air, 20°C	0.2417	0.1684	1.402
Ammonia	0.5356	0.391	1.336
Bromine, 19°–388°	0.0555	0.0429	....
Carbon dioxide, 0°	0.2010	0.172	1.30
Carbon disulphide, 86°–190°	0.1596	0.131	1.239
Carbon monoxide, 23°–99°	0.2425	0.1736	1.401
Chlorine	0.1241	0.0928	1.33
Hydrogen	3.4090	2.411	1.42
Methane	0.5929	0.486	1.313
Nitrogen, 0°C	0.2350	0.1727	1.41
Nitrous oxide	0.2262	0.181	1.324
Oxygen	0.2175	0.1723	1.41 –
Sulphur dioxide	0.1544	0.123	(500°) 1.2
Water	0.4805	0.370	1.305
Hydrochloric acid	0.1867	....	....
Acetylene	....	....	1.26
Argon, 20°–90°C	0.123	....	....
Iodine, 206°–377°C	0.034	....	....
Nitric oxide, 13°–172°	0.232	....	1.394
Nitrogen peroxide, 27°–67°	1.625	....	(150°) 1.31
Sulphuretted hydrogen, 20° –206°	0.245	....	1.340
Ethane	....	....	1.22
Ethylene	0.404	....	1.264
Benzene, 34°–115°	0.299	....	(20°) 1.40
Turpentine, 179°–249°	0.506	....	....

Specific Heat of Gases[1]

(Calories per gram of gas at t°C. (absolute temperature = $t + 273$))

	According to Richards	According to Damour
Nitrogen (to 2000°C.)	$0.2405 + 0.0000214t$	$0.2438 + 0.0000214t$
Nitrogen (2000°–4000°C.)	$0.2044 + 0.000057t$	....
Oxygen (to 2000°C.)	$0.2104 + 0.0000187t$	$0.2135 + 0.0000187t$
Oxygen (2000°–4000°C.)	$0.1788 + 0.00005t$	....
Water vapor	$0.42 + 0.000185t$	$0.447 + 0.000162t$
Carbon dioxide	$0.19 + 0.00011t$	$0.194 + 0.000084t$
Sulphur dioxide	$0.125 + 0.0001t$	....
Carbon monoxide	$0.2405 + 0.0000214t$	$0.2438 + 0.0000214t$
Hydrogen	$3.37 + 0.0003t$	$3.412 + 0.000300t$
Methane	....	$0.381 + 0.0000234t$
Hydrogen (2000°–4000°C.)	$2.75 + 0.0008t$	....

[1] Somermeier's "Coal."

Table of Mean Specific Heats

Calories per gram of gas

	Richards		Damour		Lewis & Randell	
	0°–300°	0°–1000°	0°–300°	0°–1000°	0°–300°	0°–1000°
Nitrogen	0.247	0.262	0.250	0.265	0.247	0.259
Oxygen	0.216	0.229	0.219	0.232	0.216	0.227
Carbon dioxide	0.223	0.300	0.219	0.278	0.219	0.248
Water vapor	0.476	0.605	0.497	0.610	0.469	0.512
Carbon monoxide	0.247	0.262	0.250	0.265	0.247	0.260
Air	0.240	0.257	0.247	0.258	0.240	0.252
Sulphur dioxide	0.155	0.225	....	....	0.150	0.170
Hydrogen	3.460	3.670	3.502	3.712	3.41	3.57
Methane	....	....	0.723	0.986	....	....

Specific Heat of Gases, By Volume[1]

	Cal. per cu. m. of gas, per deg. C.	Lb.-cal. per cu. ft. of gas, per deg. C.
Nitrogen	$0.303 + 0.000027t$	$0.0189 + 0.0000017t$
Water vapor	$0.34 + 0.00030t$	....
Carbon dioxide	$0.37 + 0.00044t$	....
Carbon monoxide	$0.2575 + 0.000072t$	....
Sulphur dioxide	$0.444 + 0.00054t$	....
Hydrogen	$0.303 + 0.000027t$	$0.0189 + 0.0000017t$
Hydrogen (2000°–4000°)	$0.2575 + 0.000072t$	$0.0161 + 0.0000045t$
Oxygen	$0.303 + 0.000027t$	$0.0189 + 0.0000017t$

Total Heat Contained at Melting Point of Metals[1]

The heat is expressed in calories necessary to heat 1 gram of the metal to its melting point from 0°C. The latent heat of fusion is then the difference between the heat in the solid and that in the liquid phases.

Element	Melting point	Heat in solid	Heat in liquid	Latent heat of fusion
Aluminum	625.0	158.3	258.3	100.0
Alumina	2200.0	882.0	933.0	51.0
Antimony	632.0	34.1	74.3	40.2
Bismuth	267.0	9.0	21.0	12.0
Cadmium	321.7	18.81	31.83	13.02
Copper	1085.0	117.0	162.0	45.0
Gold	....	34.63	50.93	16.3
Iron	1450.0	300.0	369.0	69.0
Lead	326.0	11.6	15.6	4.0
Palladium	962.0	64.8	89.15	24.35
Platinum	1775.0°	75.2	102.4	27.2
Tin	....	14.34	28.16	13.82
Zinc	420.0	45.2	67.8	22.6

[1] J. W. Richards, "Metallurgical Calculations."

L HEAT CONTAINED IN CERTAIN SILICATES WHEN MELTED[1]

		Melting point	Heat in solid	Heat in liquid	Latent heat of fusion
silicate (olivine)........	Mg_2SiO_4	1400°	520	650	130
silicate (enstatite)......	$MgSiO_3$	1300°	403	528	125
m. silicate (microcline)...	$KAlSi_3O_8$	1170°	....	....	83
m. silicate (orthoclase)...	$KAlSi_2O_6$	1200°	....	....	100
. silicate (anorthite).....	$CaAl_2Si_2O_8$	1220°	358	458	100
licate (wollastonite)......	$CaSiO_3$	1250°	360	460	100
es. silicate (malacolite)..	$Ca_3MgSi_4O_{12}$	1200°	319	413	94
es. silicate (diopside)	$CaMgSi_2O_6$	1225°	344	444	100
e (fayalite)..............	Fe_2SiO_4	1040°	310	395	85
silicate (garnet).........	$Fe_3Al_2Si_3O_{12}$	1145°	....	....	......

eral, the specific heat of a slag (silicate) may be cal- s the mean of the specific heat of the constituents, ick approximation is to take it at any temperature as

$$S_0(1 + 0.00078t)$$

any range of temperature as being

$$S_1(1 + 0.00039[t_1 - t_2])$$

is specific heat at 0° and S_1 is specific heat at t_1.

SOLUBILITY OF SALTS AT 10°C. AND BOILING[2]

One part requires for solution	Cold water	Hot water
sulphate (+$18H_2O$)..................	1.052	0.088
alum (+$12H_2O$)...................	10.92	0.24
carbonate.........................	4.0	1.5
chloride..........................	3.04	1.37
chlorplatinate....................	150.0	80.0
nitrate...........................	0.54	0.19
oxalate...........................	22.22	2.45
sulphate..........................	1.358	1.026
oride (+$2H_2O$)....................	3.00	1.66
drate (+8Aq)......................	21.32	0.02
rate..............................	12.50	3.11
....	51.3(0°)	2.94
....	30.0	31.9(30°)
chloride..........................	1.08	0.75
rbonate...........................	Insoluble	....
loride (fused)....................	1.667	0.649
droxide...........................	600.0	....
trate.............................	1.07(0°)	0.28(152°)
ide...............................	750.0	1500.0
lphate (+$2H_2O$)...................	3.86(18°)	451.0
id (CrO_3)......................	0.607	....
lphate (+$18H_2O$)..................	0.833(20°)	....
sulphate (+$5H_2O$).................	2.9(20°)	....
phate (+$5H_2O$)....................	2.7	0.49

le is compiled from RICHARD's "Metallurgical Calculations."
R and BICKNELL's "Chemical and Metallurgical Handbook."
tables of solubility see the table of "Properties of Compounds," "Properties of Precipitates," p. 328.

SOLUBILITY OF SALTS AT 10°C. AND BOILING. *Continued*

One part requires for solution	Cold water	Hot water
Copper acetate	14.28	5.05
Copper nitrate	0.78	....
Ferrous chloride (+$4H_2O$)	0.68	....
Ferric chloride	0.63	0.18
Ferrous sulphate (+$7H_2O$)	1.64	0.27
Lead acetate (+$3H_2O$)	1.00(40°)	0.5
Lead chloride	105.0	20.0
Lead nitrate	2.07	0.72
Lead sulphate	12,500	....
Lithium chloride	1.24	0.7
Magnesium carbonate (+$3H_2O$)	552(16°)	....
Magnesium chloride (+$6H_2O$)	0.6	0.27
Magnesium oxide	50,000	....
Magnesium sulphate crystals	3.17	1.25
Manganous chloride	1.61	0.81
Manganous sulphate (+$4H_2O$)	0.79	1.07
Mercuric chloride	15.22	1.85
Oxalic acid	8.69	1.00
Potassium bitartrate	244.0	16.4
Potassium alum (+$12H_2O$)	10.50	0.28
Potassium bicarbonate	3.0	....
Potassium bichromate	10.0	1.06
Potassium bromide	1.76	0.98
Potassium carbonate	0.91	0.64
Potassium chlorplatinate	89.3(20°)	19.3
Potassium chlorate	16.58	1.66
Potassium chloride	3.13	1.77
Potassium chromate	1.64	1.22
Potassium cyanide	0.82	....
Potassium ferricyanide	2.73	1.29
Potassium ferrocyanide	3.4(15°)	1.1
Potassium hydrate	0.50	....
Potassium iodide	0.7(20°)	0.5
Potassium nitrate	4.74	0.4
Potassium oxalate (acid)	40.0	10.0
Potassium permanganate	16.0(15°)	....
Potassium sulphate	10.31	3.82
Potassium sulphite	1.00	....
Potassium bitartrate	250.0	9.52
Silver nitrate	0.4(19°)	0.09
Sodium acetate (+$3H_2O$)	4.0(6°)	1.7(48°)
Sodium bicarbonate	10.0	....
Sodium bisulphate	3.5	....
Sodium borate	21.5	1.82
Sodium bromide	1.13	0.87
Sodium carbonate (+$10H_2O$)	1.61	0.4(30°)
Sodium chlorate	1.0(20°)	0.49
Sodium chloride	2.78	2.53
Sodium hydrate	1.64	....
Sodium hyposulphite (+$5H_2O$)	0.6	....
Sodium nitrate	1.14(20°)	0.56
Sodium acid phosphate ($Na_2HPO_4{\cdot}12H_2O$)	6.7(15°)	0.4
Sodium sulphate (+$10H_2O$)	4.34	0.32(33)°
Sodium sulphite	4.00	1.00
Strontium chloride	2.07	0.98
Strontium hydrate (+$8H_2O$)	55.5(20°)	2.1
Strontium nitrate	1.82	0.99
Stannous chloride	0.37	....
Tartaric acid	1.31	0.50
Zinc chloride (+$2H_2O$)	0.25(15°)	....
Zinc sulphate (+$7H_2O$)	0.72	0.15

Solubilities of Solids in Water

S = number of grams of anhydrous substance which when dissolved in 100 grams of water make a saturated solution at the temperature stated.

p = number of grams of anhydrous substance per 100 grams of saturated solution.

Substance	0°C.	10	15	20	40	60	80	100
Am. chlor., NH_4Cl, S	29.4	33.3	35.2	37.2	45.8	55.2	65.6	77.3
Barium chlor., $BaCl_2 \cdot 2H_2O$, S	31.6	33.3	34.5	35.7	40.7	46.4	52.4	58.8
Barium hydrate, $Ba(OH)_2 \cdot 8H_2O$, S	1.67	2.48	3.23	3.89	8.22	20.94	101.4	......
Bromine (liquid),[1] Br_2, S	4.17	3.74	3.65	3.58	3.45	.....	.....	.....
Cadmium sulphate, $CdSO_4 \cdot \frac{8}{3}H_2O$, S	76.5	76.0	76.3	76.6	78.5	83.7	70.2[2]	60.77[2]
Calcium hydrate, $Ca(OH)_2$, S	0.185	0.176	0.170	0.165	0.141	0.116	0.094	0.077
Copper sulphate, $CuSO_4 \cdot 5H_2O$, S	14.3	17.4	18.8	20.7	28.5	40.0	55.0	75.0
Lithium carbonate, Li_2CO_3, S	1.54	1.43	1.38	1.33	1.17	1.01	0.850	0.720
Mercuric chloride, $HgCl_2$, p	3.50	4.50	5.00	5.40	9.30	14.0	23.1	38.0
Potass. chloride, KCl, S	27.6	31.0	32.4	34.0	40.0	45.5	51.1	56.7
Potass. bromide, KBr, S	53.5	59.5	62.5	65.2	75.5	85.5	95.0	104.0
Potass. iodide, KI, S	127.5	136.0	140.0	144.0	160.0	176.0	192.0	208.0
Potass. hydrate, $KOH \cdot 2H_2O$, S	97.0	103.0	107.0	112.0	138.0[3]	.....	.....	178.0[3]
Potass. nitrate, KNO_3, S	13.3	20.9	25.8	32.0	64.0	110.0	169.0	246.0
Silver nitrate, $AgNO_3$, S	122.0	170.0	196.0	222.0	376.0	525.0	669.0	952.0
Sodium carbonate, $Na_2CO_3 \cdot 10H_2O$, S	7.0	12.5	16.4	21.5	46.1[4]	46.0[4]	45.8[4]	45.5[4]
Sodium chloride, $NaCl$, S	35.7	35.8	35.9	36.0	36.6	37.0	38.0	39.0
Sodium sulphate $Na_2SO_4 \cdot 10H_2O$, S	5.0	9.0	13.4	19.4	49.0[5]	45.0[5]	44.0[5]	42.0[5]
Strontium chloride, $SrCl_2 \cdot 6H_2O$, S	43.0	48.0	50.0	53.0	65.0	82.0	91.0[6]	101.0[6]

The above formulas are those of the solid phases that are in equilibrium with the solution. The figures are from SEIDELL'S "Solubilities of Inorganic and Organic Substances." D. Van Nostrand Co., New York.

[1] Very soluble in ammonium-acetate solution.
[2] Solid phase becomes $CdSO_4 \cdot H_2O$ at 74°.
[3] Becomes $KOH \cdot \frac{3}{2}H_2O$ at 32.5° and $KOH \cdot H_2O$ at 50°.
[4] Becomes $Na_2CO_3 \cdot H_2O$ at 35°.
[5] Becomes Na_2SO_4 at 32.38°.
[6] Becomes $SrCl_2 \cdot 2H_2O$ at 70°.

Solvents for Metals

Gold	Aqua regia.
Platinum	Aqua regia.
Silver	HNO_3, boiling H_2SO_4.
Lead	HNO_3, boiling concen. H_2SO_4 slightly.
Mercury	HNO_3, boiling H_2SO_4.
Bismuth	HNO_3.
Copper	HNO_3.
Cadmium	HNO_3.
Arsenic	Aqua regia, HNO_3 to oxide.
Antimony	Aqua regia, HNO_3 to oxide.
Tin	HCl, HNO_3 to oxide.
Iron	HCl, dilute H_2SO_4, not by conc
Aluminum	HCl, HNO_3, H_2SO_4, alkalis.
Nickel	HNO_3
Cobalt	HNO_3
Manganese	HCl.
Zinc	HCl, HNO_3, H_2SO_4, alkalis.

In Dilute Solution (Fifth Normal or More Dilute)[1]

1. Copper is acted upon by cold dilute hydrochloric acid to a much greater extent than by sulphuric or nitric acids. Each of the last-named acids attacks the metal to about the same extent.
2. Aluminium is slowly attacked by dilute nitric acid and sulphuric acid.
3. Lead is more rapidly attacked by hydrochloric acid than by sulphuric acid, the action of the latter acid being negligible.
4. Tin is soluble in caustic soda and in sodium carbonate solution, but not in ammonia.

Action of Acetylene upon Metals (*Chem. Zeit.*, 1915, 89, 42). —In acetylene installations explosions have sometimes occurred which have been attributed to the formation of explosive compounds of acetylene with the metal of the fittings. In a series of experiments it was found that pure dry acetylene in contact for 20 months with the following metals had no action upon them: zinc, tin, lead, iron, copper, nickel, brass, German silver, phosphor bronze, aluminum bronze, type metal, solder. With pure moist acetylene nickel and copper were both attacked. Unpurified moist gas, as obtained in the ordinary way from commercial carbide, had no appreciable action on tin, German silver, aluminum bronze, type metal or solder, but had a distinct action on zinc, lead, brass, much more on iron and bronze, and still more on phosphor bronze, while the action on copper was very rapid; but it is stated that in no case were explosive substances produced. It is recommended that metal fittings used in connection with acetylene should be coated with nickel or tin.

[1] A. J. Hale and H. S. Foster, *Journ. Soc. Chem. Ind.*, May 15, 1915.

Solubility of Air in Water[1]

0 cc. of water saturated with air at 760 mm. pressure
n the following volumes of dissolved gas (calculated to
e at 0°C. and 760 mm.).

	Temperature of water						
	0°	5°	10°	15°	20°	25°	30°
i, cc.	10.19	8.9	7.9	7.0	6.4	5.8	5.3
en, argon, etc.	19.0	16.8	15.0	13.5	12.3	11.3	10.4
above, cc.	29.2	25.7	22.8	20.5	18.7	17.1	15.7
it. oxygen in dissolved air (by ne)	34.9	34.7	34.5	34.2	34.0	33.8	33.6

Solubility of Sulphur Dioxide in Water

(760 mm. pressure[2])

rature of water, deg. C.	20	30	40	50	60	70	80	90	100
r cent. dissolved	8.6	7.4	6.1	4.9	3.7	2.6	1.7	0.9	0.0

Solubility of Gases in Water

(760 mm. pressure[3])

	Volumes, 0°C.	Volumes, 15°C.	Volumes, 30°C.	Volumes, 60°C.
i	0.0489	0.03415	0.02608	0.019
en	0.02388	0.01686	0.01380	0.0100
i monoxide	0.03537	0.02543	0.01998	0.015
i dioxide	1.713	1.019	0.665	0.36
iia	1300.0	802.0	598.0 / 28°	....
....	0.058	0.041	0.030	....
ie	....	2.63	1.77	1.0
....	0.0150	0.0139	0.0138	....
gen	0.0215	0.0188	0.018 / 20°	....
hloric acid	506.0	458.0	411.0	339.0
s oxide	....	0.74	0.63 / 20°	....
oxide	0.074	0.0515	0.040	0.029
retted hydrogen	4.68	3.05	2.67 / 20°	....
r dioxide	79.8	47.3	27.2	18.8 / 40°
ene	....	1.15	....	....
oromic acid	....	581.0	....	....
....	....	0.02045	....	....
ie	....	28.4	....	....

e majority of the above cases the gases are in equilibrium with the
t 760° mm. pressure.

re and Laby's "Chemical and Physical Constants."
fman's "General Metallurgy."
npiled from various authorities.

The Properties of the Principal Inorganic Compounds

Substance	Formula	Molecular weight O = 16	Specific gravity	Melting point, deg. C.	Boiling point, deg. C.	Solubility (parts solid to parts water)			
						Cold water	Hot water	Alcohol	Acids
Aluminum	Al	27.1	2.50–2.68	850	...	i	i	i	i cold dil. H_2SO_4, cold. HNO_3, HCl.
Bromide	$AlBr_3$	266.86	2.54	93	265	s	s	...	s
Chloride	$AlCl_3 \cdot 6H_2O$	241.58	...	182	190	4:1	s	1:2	s
Fluoride	AlF_3	84.1	3.1	...	...	i	i	...	i
Hydrate	$Al(OH)_3$	78.12	2.3	Decomp.	...	i	i	...	s
Iodide	$AlI_3 \cdot 6H_2O$	515.96	2.63	185	360	s	s	s	s–CS_2
Nitrate	$Al_2(NO_3)_6 \cdot 15H_2O$	694.50	...	73	Decomp. 134	v.s.	s	s	...
Oxide	Al_2O_3	102.2	4.0	White heat	...	i	i	i	...
Phosphate	$AlPO_4$	122.04	...	...	...	i	i	...	s conc. acids
Sulphate	$Al_2(SO_4)_3 \cdot 9H_2O$	504.55	1.62	Decomp.	Decomp. redness	85:100	130:100	i	s
Sulphide	Al_2S_3	150.41	...	...	...	Decomp.	...	...	...
Ammonia	NH_3	17.03	...	−75	−33.5	1050:1	730 at 15°	...	...
Ammonium:									
Acetate	$NH_4C_2H_3O_2$	77.07	...	Decomp. 89	...	14.8:100	s	s	...
Alum	$NH_4Al(SO_4)_2 \cdot 12H_2O$	453.47	1.63	...	...	9:100	422:100	i	...
Arsenate	$(NH_4)_3AsO_4 \cdot 3H_2O$	247.1	...	...	...	s	s	...	s
Bichromate	$(NH_4)_2Cr_2O_7$	252.08	...	...	...	v.s.	v.s.	...	...
Bromide	NH_4Br	97.96	2.33	60	...	66:10	128 v.s.	l.s.	...
Carbonate	$(NH_4)_2CO_3$	96.08	...	Decomp.	...	25:100	v.s.	l.s.	...
Chloride	NH_4Cl	53.46	1.52	Sublimes	...	37:100	1:1	12:100	...
Chlorplatinate	$(NH_4)_2PtCl_6$	444.06	3.06	Decomp.	...	0.67:100	...	i	...
Chromate	$(NH_4)_2CrO_4$	136.08	1.88	Decomp.	...	Decomp.	Decomp.	...	...
Fluoride	NH_4F	37.04	...	...	...	v.s.	v.s.	l.s.	...
Hydrate	NH_4OH	35.05	...	...	...	v.s.	v.s.	s	...
Iodide	NH_4I	144.96	...	Sublimes	...	v.s.	v.s.	v.s.	...
Magnes. arsenate	$NH_4MgAsO_4 \cdot H_2O$	198.33	...	Decomp.	...	0.02:100	i	i	s

Ammonium:									
Magnes. phosph.	$NH_4MgPO_4 \cdot 6H_2O$	245.52		Decomp.		0.005:100	i	i	s
Molybdate	$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$	1236.32	2.4–2.9	Decomp.		Decomp.	Decomp.	i	s
Nitrate	NH_4NO_3	80.05	1.71	152	210decomp.	200:100	1:1	1:2	
Nitrite	NH_4NO_2	64.05	1.7	Decomp.		s	s		
Oxalate	$(NH_4)_2C_2O_4 \cdot H_2O$	142.1	1.5			1:25	v.s.		
Phosphate	$(NH_4)_2HPO_4$	132.13	1.5			1:4	s	i	
Phospho. molyb.	$(NH_4)_3PO_4 \cdot 10MoO_3 \cdot 3H_2O$	1644.26				0.03:100	i	i	i–HNO_3
Platin. chlor.	$(NH_4)_2PtCl_6$	443.98	3.065	Decomp.		1:150	1:80	0.005:100	s
Sulphate	$(NH_4)_2SO_4$	132.15	1.77	140	Sublimes	75:100	1:1	l.s.	
Sulphydrate	NH_4HS	51.12		Sublimes		s	s		
Sulphocyanate	NH_4SCN	76.12				162:100	v.s.	s	
Antimony	Sb	120.2	6.72	450	White heat				s–aq. req. i–HCl.
Bromide	$SbBr_3$	359.96	4.15	93	280	Decomp.	Decomp.		
Chloride	$SbCl_5$	297.50		−6	102.5	Decomp.	Decomp.		
Hydride	SbH_3	123.22		−91.5	−18	20:100	vols.		
Iodide	SbI_3	500.96	4.85	167	401	Decomp.	Decomp.		
Ous chloride	$SbCl_3$	226.6	2.67	72	223	s	Decomp.		s–HCl
Ous oxide	Sb_2O_3	288.04	3.7–5.4	Red heat	Sublimes	i	i	i	s–HCl
Ous sulphide	Sb_2S_3	336.61	4.62	Red heat		i	i	i	s–NH_4HS
Oxide	Sb_2O_5	320.4	5.6	360	Decomp.	i	i	i	s
Sulphide	Sb_2S_5	400.75		Red heat		i	i	i	s–NH_4HS
Trichloride	$SbCl_3$	226.58	3.06	73.2	223	816:100	∞		
Oxy chloride	$SbOCl$	171.66		Decomp.	Decomp.	i	i	i	s–HCl
Oxy sulphate	$(SbO)_2SO_4$	368.47				Decomp.	Decomp.		
Arsenic:									
Amorp.	As	74.96	4.71	Sublimes 130		i	i	i	
Cryst.	As	74.96	5.75	Sublimes 130		i	i	i	
Oxide	As_2O_5	229.92		Red heat	Decomp.	15:10		s	
Sulphide	As_2S_5	310.27			Sublimes	i	i		s–alkalies
Arsenious:									
Bromide	$AsBr_3$	314.72	3.66	31	220	Decomp.	Decomp.		s–HCl
Chloride	$AsCl_3$	181.34	2.20	−18	132	Decomp.	Decomp.		s–HCl
Fluoride	AsF_3	131.96	2.73	−8.5	63	Decomp.	Decomp.		
Iodide	AsI_3	455.72	4.39	146	404	Decomp.	Decomp.		

The Properties of the Principal Inorganic Compounds. *Continued*

Substance	Formula	Molecular weight O = 16	Specific gravity	Melting point, deg. C.	Boiling point, deg. C.	Solubility (parts solid to parts water)			
						Cold water	Hot water	Alcohol	Acids
Arsenious:									
Oxide	As_2O_3	197.92	3.7–3.74	Subl. 218	...	3.7:100	1:10	...	s–HCl
Realgar	As_2S_2	214.06	3.5	...	...	i	i	...	i–HCl
Sulphide	As_2S_3	246.13	3.48	...	...	i	i	...	i–HCl
Arsine	AsH_3	77.98	3.48	−113	−54.8	l.s.	i	...	s–alkalies
Auric:									
Bromide	$AuBr_3$	436.96	...	...	...	s	s	...	...
Chloride	$AuCl_3·2H_2O$	339.62	...	Decomp.	...	68:100	s	s	...
Cyanide	$Au(CN)_3.6H_2O$	383.33	...	...	...	v.s.	v.s.	s	...
Hydrate	$Au(OH)_3$	248.22	...	Decomp.	...	i	i	...	s–HNO_3
Iodide	AuI_3	577.96	...	Decomp.	...	i	...	...	...
Oxide	Au_2O_3	442.4	...	Decomp.	...	i	i	...	s–HCl
Sulphide	Au_2S_3	490.91	...	Decomp.	...	...	...	...	s–NH_4HS
Aurous:									
Chloride	AuCl	232.66	...	Decomp.	...	Decomp.	Decomp.	...	...
Cyanide	AuCN	223.21	...	Decomp.	...	i	i	i	...
Iodide	AuI	324.12	...	Decomp. at 120	...	...	...	...	...
Oxide	Au_2O	410.7	...	Decomp.	...	i	i	...	s–HCl
Sulphide	Au_2S	426.77	...	...	...	i	i	...	s–NH_4HS
Barium	Ba	137.37	...	Red heat	...	Decomp.	Decomp.	...	...
Bromide	$BaBr_2·2H_2O$	333.24	3.85	...	...	1:1	1:0.67	s	...
Carbonate	$BaCO_3$	197.37	4.3	795	Decomp. 1450	i	i	i	s
Chlorate	$Ba(ClO_3)_2·H_2O$	322.31	...	...	...	1:4	1:0.80	i	...
Chloride	$BaCl_2.2H_2O$	244.32	3.05	847	...	36:100[1]	78:100[1]	i	...
Chromate	$BaCrO_4$	253.37	...	...	...	i	i	...	s
Hydrate	$Ba(OH)_2·H_2O$	189.40	4.5	Below redness	...	3.48:100[1]	1:2[1]	l.s.	s
Iodide	$BaI_2·2H_2O$	427.24	4.92	740	...	1:5	1:35	s	...
Nitrate	$Ba(NO_3)_2$	261.39	3.24	575	...	1:12	1:3	i	l.s.
Oxide	BaO	153.37	5.4	...	...	s	s	...	s
Peroxide	BaO_2	169.37	...	Red heat	...	i	Decomp.	...	s–HCl
Phosphate	$Ba_3(PO_4)_2$	602.19	...	...	...	i	i	...	s

Sulphate........	$BaSO_4$	[illegible]	[illegible]	....	....	[illegible]	[illegible]	[illegible]	[illegible]
Sulphide.......	BaS	169.44	....	....	....	Decomp.	Decomp.	i	s
Sulphydrate....	$Ba(SH)_2$	203.53	....	....	....	s	s	....	s
Beryllium:									
Bromide.......	$BeBr_2$	168.94	....	601	....	....	....	....	
Chloride.......	$BeCl_2$	80.02	....	600	....	....	....	....	....
Sulphate.......	$BeSO_4 \cdot 4H_2O$	177.23	1.7	Decomp.	Red heat	44:100	....	....	....
Bismuth.........	Bi	208.0	9.8	270	....	....	....	....	s
Bromide.......	$BiBr_3$	447.76	5.6	200	453	Decom. with excess	....	....	s-HNO_3
Chloride.......	$BiCl_3$	314.38	4.6	225	429		....	....	s-HCl
Hydrate.......	$Bi(OH)_3$	259.02	....	....	....	i	i	....	s
Iodide.........	BiI_3	588.76	....	Sublimes	....	i	Decomp.	....	....
Nitrate........	$Bi(NO_3)_3 \cdot 5H_2O$	484.11	2.8	74	Decomp. 80	Decomp.	....	....	....
Oxide.........	Bi_2O_3	464.0	8.2–9.0	820	....	i	i	....	....
Sulphate.......	$Bi_2(SO_4)_3$	704.21	....	Decomp.	....	Decomp.	....	....	....
Sulphide.......	Bi_2S_3	512.21	7–7.8	Decomp.	....	i	i	....	....
Boric:									
Acid..........	H_3BO_3	62.02	1.43	Decomp. 100	....	1:25	1:3	1:6	....
Anhydride.....	B_2O_3	70.00	1.83	577	....	1:40	16:100	s	....
Bromide.......	BBr_3	250.76	2.69	Liquid	90	Decomp.	....	....	....
Chloride.......	BCl_3	117.38	1.35	Liquid	17	Decomp.	....	....	....
Fluoride.......	BF_3	68.00	....	−127	−101	s	....	....	....
Boron..........	B	11.0	2.68	....	....	i	i	i	....
Bromine........	Br	79.92	3.19	−25	58.6	s	s	....	....
Cadmium.......	Cd	112.40	8.69	320	860	....	....	....	....
Bromide.......	$CdBr_2$	272.24	4.7–4.9	571	809	49:100	....	....	s
Carbonate.....	$CdCO_3$	172.40	4.49	....	....	i	i	....	....
Chloride.......	$CdCl_2 \cdot 2H_2O$	219.36	....	590	900	14:10[1]	15:10[1]	s	s
Hydrate.......	$Cd(OH)_2$	144.42	....	Decomp.	....	i	i	....	s
Nitrate........	$Cd(NO_3)_2 \cdot 4H_2O$	308.48	2.4	59.5	132	127:100	....	....	....
Oxide.........	CdO	128.40	6.95	....	....	i	i	....	....
Sulphate.......	$CdSO_4 \cdot 4H_2O$	280.53	3.05	....	....	76.6:100[1]	v.s.	....	....
Sulphide.......	CdS	144.47	4.8	Red heat	....	i	i	....	i-dil. acids; s-conc. acids

[1] The anhydrous salt is referred to.

THE PROPERTIES OF THE PRINCIPAL INORGANIC COMPOUNDS. *Continued*

Substance	Formula	Molecular weight O = 16	Specific gravity	Melting point, deg. C.	Boiling point, deg. C.	Solubility (parts solid to parts water)			
						Cold water	Hot water	Alcohol	Acids
Cæsium:									
Carbonate	Cs_2CO_3	325.62	.....	Decomp. 610	.....	v.s.	v.s.	.....	.....
Chloride	CsCl	168.27	3.97	631	.....	174:100	.....	.....	.....
Hydride	CsH	133.82	2.7	Decomp.	.....	Decomp.	.....	.....	.....
Hydroxide	CsOH	149.82	4.02	Red heat	.....	s	.....	.....	.....
Nitrate	$CsNO_3$	194.82	3.69	414	Decomp.	15:100	.....	.....	.....
Calcium	Ca	40.07	1.58	Red heat	.....	Decomp.	Decomp.	Decomp.	.....
Bromide	$CaBr_2$	199.91	.....	3.3	760	800	125:100	.....	s
Carbonate	$CaCO_3$	100.07	2.7–2.9	Decomp. 825	.....	i	i	i	s
Chloride	$CaCl_2$	110.99	2.2	780	.....	72:100	65:10	s	s
Chlorid of lime	$CaOCl_2$	126.99	.....	Decomp.	.....	s	s	.....	.....
Fluoride	CaF_2	78.07	3.15	.....	.....	1:2000	.....	.....	s
Hydrate	$Ca(OH)_2$	7.02	2.08	Decomp.	.....	0.13:100	0.1:100	i	s
Iodide	CaI_2	293.91	4.9	740	710	192:100	.....	.....	.....
Nitrate	$Ca(NO_3)_2$	164.29	1.82	Decomp. 132	.....	54.8:100	.....	.....	.....
Oxide	CaO	56.07	3.2	Infusible		1:778	1:1270	i	s
Phosphate	$Ca_3(PO_4)_2$	310.29	3.18	.....	.....	0.003:100	i	.....	s
Sulphate	$CaSO_4 \cdot 2H_2O$	172.17	2.31	Decomp.	.....	1:500	1:460	i	l.s.
Carbon	C	12.00	2.2–3.5	.....	.....	i	i	i	i
Tetrachloride	CCl_4	153.84	1.582	−23.8	76.7	i	.....	.....	.....
Carbonic:									
Acid	H_2CO_3	62.02	.....	.....	.....	s	s	.....	.....
Anhydride	CO_2	44.00	.....	−78.5	.....	1:1 vol.	.....	.....	.....
Disulphide	CS_2	76.14	1.29	−110	46.6	i	.....	s	.....
Oxide	CO	26.00	.....	−207	−190	1:30 vols.	.....	.....	.....
Cerium(ic) oxide	CeO_2	172.25	6.74	.....	.....	i	.....	.....	.....
Cerium(ous):									
Chloride	$CeCl_3$	246.63	3.88	.....	.....	s	.....	.....	.....
Oxide	Ce_2O_3	328.50	6.9	.....	.....	i	.....	.....	.....
Sulphate	$Ce_2(SO_4)_3 \cdot H_2O$	586.73	3.22	.....	.....	16.5:100	.....	.....	.....
Chloric acid	$HClO_3 \cdot 7H_2O$	210.58	1.28	40	Decomp.	v.s.	.....	.....	.....

									H_2SO_4
Chromic:									
Anhydride	CrO_3	100.00	2.74	190	Decomp.	165.5:100	v.s.	s	s
Chloride	Cr_2Cl_6	316.76	2.76	....	Sublimes	l.s.	s	....	s
Hydrate	$Cr_2(OH)_6$	206.04	....	Decomp.	Decomp.	i	i	....	s–alk.,acids
Oxide	Cr_2O_3	152.00	5.21	White heat	....	i	i	i	i
Sulphate	$Cr_2(SO_4)_3 \cdot 18H_2O$	716.50	1.87	Decomp. 100	....	s	s	s	s
Chrome:									
Alum	$K_2Cr_2(SO_4)_4 \cdot 24H_2O$	998.82	....	....	....	1:8[1]	s	....	s
Green	Cr_2O_3	152.00	5.21	White heat	....	i	i	i	i
Orange	$PbO \cdot PbCrO_4$	546.20	....	....	....	i	i	....	s–HNO_3
Yellow	$PbCrO_4$	323.10	....	....	....	i	i	....	s–HNO_3
Cobalt	Co	58.97	8.95	White heat	....	i	i	....	s
Cobaltic:									
Chloride	Co_2Cl_6	330.70	2.94	Decomp.	....	s	....	....	....
Oxide	Co_2O_3	165.94	5.6	Decomp. at red heat.	....	i	i	i	....
Cobaltous:									
Chloride	$CoCl_2$	129.89	1.84	Subl. 87	....	29.5:100	s	....	....
Hydrate	$Co(OH)_2$	92.99	3.6	....	....	i	i	....	....
Oxide	CoO	74.97	5.7	....	....	i	i	i	....
Sulphate	$CoSO_4 \cdot 7H_2O$	281.15	1.92	96.8	....	36:100[1]	65:100[1]	i	....
Columbium pentachloride	$CbCl_5$	270.8	4.4	194	240.5	Decomp.	....	....	....
Copper	Cu	63.57	8.85–8.94	1098	....	i	i	i	s
Cupric:									
Acetate	$Cu(C_2H_3O_2 \cdot H_2O$	199.64	....	Decomp. at 240	....	1:131	2:10	1:14	s
Carbonate	$CuCO_3$	123.57	....	Decomp.	....	i	i	i	s
Chloride	$CuCl_2 \cdot 2H_2O$	170.52	2.47	498	Decomp. red.	7:10[1]	v.s.	s	s
Hydrate	$Cu(OH)_2$	97.59	....	Decomp.	....	i	i	i	s
Nitrate	$Cu(NO_3)_2$	187.59	2.17	114.5	170	5:4	v.s.	v.s.	s
Oxide	CuO	79.57	6.3	....	....	i	i	i	s
Sulphate	$CuSO_4 \cdot 5H_2O$	249.72	2.27	Decomp. at red heat	....	1:5[1]	2:1[1]	i	s

[1] The anhydrous salt is referred to.

THE PROPERTIES OF THE PRINCIPAL INORGANIC COMPOUNDS. *Continued*

Substance	Formula	Molecular weight O = 16	Specific gravity	Melting point, deg. C.	Boiling point, deg. C.	Solubility (parts solid to parts water) Cold water	Hot water	Alcohol	Acids
Cupric:									
Sulphide	CuS	95.64	...	...	...	i	i	i	i-dil. ac.
Cuprous:									
Chloride	Cu_2Cl_2	198.06	3.7	410	1000	l.s.	...	...	s-HCl, NH_4OH.
Oxide	Cu_2O	143.14	5.8	Bright red	...	i	i	...	s-NH_4OH
Sulphide	Cu_2S	159.21	...	1100	...	i	i	i	s-HNO_3
Cyanogen	$(CN)_2$	52.02	Liq. 0.866	−34	−21	4.5:1 vol.	...	23:1	...
Erbium:									
Nitrate	$Er_2(SO_4)_3 \cdot 8H_2O$	767.74	3.18	...	...	23:100	...	...	...
Oxide	Er_2O_3	383.4	8.6	...	...	i	...	...	...
Ferric:									
Acetate	$Fe_2(C_2H_3O_2)_6.Aq$	...	...	Decomp.	...	i	i	...	s
Ammon. sulphate	$Fe_2(NH_4)_2(SO_4)_4 \cdot 24H_2O$	964.42	1.7	...	...	1:3	v.s.	i	s
Bromide	Fe_2Br_6	591.20	...	Sublimes	Red heat	s	s	s	s
Chloride	Fe_2Cl_6	324.44	...	301	Sublimes	91:100	v.s.	v.s.	s
Disulphide	FeS_2	119.98	...	...	...	i	i	i	s-HNO_3
Ferrocyanide	$Fe_4(FeC_6N_6)_3$	859.06	...	Decomp.	...	i	i	...	...
Hydrate	$Fe_2(OH)_6$	213.73	3.4–3.9	Decomp.	...	i	i	i	s
Nitrate	$Fe_2(NO_3)_6.18H_2O$	808.03	1.68	47.2	Decomp.	s	s	s	s
Oxalate	$Fe_2(C_2O_4)_3$	375.68	...	Decomp.	...	s	s	...	s
Oxide	Fe_2O_3	159.68	4.8–5.3	...	...	i	i	i	s-HCl
Phosphate	$Fe_2(PO_4)_2 \cdot 4H_2O$	373.82	...	...	...	i	i	i	s
Sulphate	$Fe_2(SO_4)_3 \cdot 9H_2O$	562.03	2.0	...	...	26:100[1]	Decomp.	Decomp.	s
Ferrous:									
Ammon. sulphate	$Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$	392.15	1.81	Decomp. at redness.	...	17:100	v.s.	i	s
Carbonate	$FeCO_3$	115.84	3.8			i	i		s-H_2CO_3

Ferrous:									
Hydrate	$Fe(OH)_2$	89.86	...	Decomp.	...	l.s.	...	...	s
Nitrate	$Fe(NO_3)_2$	179.86	...	Decomp.	...	s	s	...	s
Oxalate	FeC_2O_4	143.84	...	Decomp.	...	s	s	...	s
Oxide	FeO	71.84	...	...	...	i	i	...	s
Sulphate	$FeSO_4 \cdot 7H_2O$	278.02	1.88	64	Decomp.	6:10	33:10	i	s
Sulphide	FeS	87.91	...	Red heat	...	i	i	i	s
Fluorine	F	19.00	...	Gas	...	...	...	...	...
Gadolinium sulphate	$Gd_2(SO_4)_3$	602.81	4.14	...	...	2.3:100	...	...	...
Germanium:									
Chloride	$GeCl_4$	214.34	1.89	...	86	Decomp.	...	...	...
Oxide	GeO_2	104.5	4.70	...	...	0.4:100	...	...	...
Gold (see also Aurum)	Au	197.2	19.26–19.55	1100	...	i	i	i	s–Aq. reg.
Graphite	C	12.00	2.2	...	...	i	i	i	...
Hydriodic acid	HI	127.93	...	−55	−36.7	v.s.	s	s	...
Hydrobromic acid	HBr	80.93	...	−87	−65	221:100	130:100	s	...
Hydrochloric acid	HCl	36.47	1.27	−112.5	−82	500:1 vol.	s	...	...
Hydrocyanic acid	HCN	27.02	0.697	−13.8	26.5	∞	∞	∞	...
Hydrofluoric acid	HF	20.02	0.988	−92.3	19.5	v.s.	v.s.	...	...
Hydrogen	H_2	2.016	...	Gas	...	2 vol.:100	...	...	...
Peroxide	H_2O_2	34.02	1.458	−2	80.2	v.s.	...	...	...
Selenide	H_2Se	81.22	...	−64	−42	331:100 vols.	...	...	...
Iodine	I	126.92	4.95	107	175	l.s.	...	s	sol.–KI sol.
Iron (see Ferrum)	Fe	55.84	7–7.8	1050–1500	...	i	i	i	s
Lead (see also Plumbum)	Pb	207.10	11.37	334	1040	i	i	i	s–HNO_3
Iodide	PbI_2	260.94	6.12	373	861	0.04:100	...	...	...
Lime (see also Calcium)	CaO	56.07	3.2	...	...	1:778	1:1270	i	s
Litharge	PbO	223.10	9.2	Red heat	...	i	i	i	s–alk., HNO_3
Lithium	Li	6.94	0.59	180	...	Decomp.	...	...	s

The Properties of the Principal Inorganic Compounds. *Continued*

Substance	Formula	Molecular weight O = 16	Specific gravity	Melting point, deg. C.	Boiling point, deg. C.	Solubility (parts solid to parts water) Cold water	Hot water	Alcohol	Acids
Lithium:									
Carbonate	Li_2CO_3	73.88	2.11	618		1.2:100	1.5:100	i	s
Chloride	$LiCl \cdot H_2O$	60.42	2–2.07	491	Decomp.	65:100[1]	125:100[1]	v.s.	v.s.
Hydrate	$LiOH$	23.96		Red heat		l.s.			s
Nitrate	$LiNO_3$	68.95	2.3–2.4	258		3:4	v.s.	v.s.	
Phosphate	Li_3PO_4	115.86	2.4	857		0.04:100			
Sulphate	$Li_2SO_4 \cdot H_2O$	127.97	2.21	818		35:100[1]	28:100[1]	s	
Magnesium	Mg	24.32	1.74	Red heat		i	Decomp.		s
Ammon.-phos.	$NH_4MgPO_4 \cdot 6H_2O$	235.50		Decomp.		1:15,000			s
Carbonate	$MgCO_3$	84.32	3.0	Decomp.		0.01:100	i		s
Chloride	$MgCl_2 \cdot 6H_2O$	203.34	1.56	708		15:10	37:10	1:2	s
Hydrate	$Mg(OH)_2$	58.34	2.34	Decomp.		i	i		s
Nitrate	$Mg(NO_3)_2 \cdot 6H_2O$	256.44	1.46	90	143				
Oxide	MgO	40.32	3.65			0.001:100	i		s
Pyrophos.	$Mg_2P_2O_7$	222.72				i	i	i	s
Sulphate	$MgSO_4 \cdot 7H_2O$	246.50	1.75	Red heat		1:3[1]	1:14[1]	s	s
Manganese	Mn	54.93	7.2			Slowly	Decomp.		s
Dioxide	MnO_2	86.93	4.7–5.0			i	i	i	s
Manganous:									
Carbonate	$MnCO_3$	114.93	3.5	Decomp.		i	i	i	s
Chloride	$MnCl_2 \cdot 4H_2O$	197.91	1.91			15:10	65:10	53:100	s
Hydrate	$Mn(OH)_2$	88.95				i	i	i	s
Nitrate	$Mn(NO_3)_2 \cdot 6H_2O$	287.05	1.82	87.5	Decomp.	v.s.	v.s.	s	s
Oxide	MnO	70.93	5.1			i	i	i	s
Sulphate	$MnSO_4 \cdot 4$ or $7H_2O$					12:10	9:10[1]	i	s
Sulphide	MnS	87.00				i	i		s–*Aq. reg.*
Mercuric:									
Bromide	$HgBr_2$	360.44	5.7	244	Subl. 322				
Chloride	$HgCl_2$	271.52	5.42	265	300	6:100	54:100	1:3	s
Iodide	HgI_2	454.44	6.2	238	349	1:50	l.s.	0.8:100	s
Nitrate	$Hg(NO_3)_2$	324.62		Decomp.	Red heat	Decomp.			s
Oxide	HgO	216.6	11.14	Decomp.	Red heat	i	i	i	s
Sulphate	$HgSO_4$	296.67	6.47			Decomp.		i	

Mercuric:									
Sulphide	HgS	232.67		Decomp.		i	i		s–*Aq. reg.*
Mercurous:									
Chloride	Hg_2Cl_2	472.12	6.99	400–500	Sublimes	i	i	i	i-HCl
Iodide	Hg_2I_2	655.04	7.64			i	i	i	
Nitrate	$HgNO_3 \cdot 2H_2O$	298.64	4.78	Decomp.		v.s.			
Oxide	Hg_2O	417.20	8.95	Decomp.		i	i	i	
Sulphate	Hg_2SO_4	497.27		Decomp.		l.s.	Decomp.		
Mercury	Hg	200.6	13.555	−38.9	357.25			i	s
Molybdenum	Mo	96.0	8.6						s–HNO_3
Chloride	$MoCl_5$	283.30		194	268	Decomp.			
Oxide, di	MoO_2	128.0	6.4			i			
Oxide, tri	MoO_3	144.0	4.4	759	Sublimes	0.2:100			
Molybdic:									
Anhydride	MoO_3	144.0	4.39	Red heat		1:500	1:960		s–NH_4OH
Sulphide	MoS_3	192.21				i			i-HCl
Nickel	Ni	58.68	8.82	White heat					s–HCl
Carbonyl	$Ni(CO)_4$	170.68	1.32	−25	43	i			
Nickelic hydrate	$Ni(OH)_3$	109.73				i	i		s
Nickelous:									
Chloride	$NiCl_2$	129.60	2.52	Sublimes		62:100	s		s
Cyanide	$Ni(CN)_2$	110.70				i	i		s–KCN
Hydrate	$Ni(OH)_2$	92.70	4.36			i	i	i	s–KCN
Nitrate	$Ni(NO_3)_2 \cdot 6H_2O$	290.80	2.06	56.7	136.7	1:2	v.s.	s	s
Sulphate	$NiSO_4 \cdot 7H_2O$	280.86	2.03	98		1:3	6:10	i	s
Sulphide	$NiS.Aq$	90.75				i	i		s–*Aq. reg.*, i-dil. HCl.
Nitrogen	N_2	28.02	0.00126			0.0018:1 vol.		i	
Bromide	NBr_3	253.77		Liquid	Explodes				Decomp.
Chloride	NCl_3	120.39	1.65	71	Explodes	l.s.			Explodes
Dioxide	NO	30.01		−167	−153	5.1:100 vol.			s–$FeSO_4$ sol.
Iodide	NI_3	394.77		Explodes		i			Explodes
Monoxide	N_2O	44.01		−101	−88	1.3:1 vol.	l.s.	4.2:1 vol.	
Tetroxide	NO_2	46.01		−9	22	Decomp.			
Trioxide	N_2O_3	76.02		−111	0	Decomp.			
Nitric acid	$HNO_3 \cdot Aq$		1.53	−49	86	∞	∞	Decomp.	
Nitrous acid	HNO_2	47.03		−102	−89.4	∞	∞	Decomp.	

The Properties of the Principal Inorganic Compounds. *Continued*

Substance	Formula	Molecular weight O = 16	Specific gravity	Melting point, deg. C.	Boiling point, deg. C.	Solubility (parts solid to parts water)			
						Cold water	Hot water	Alcohol	Acids
Osmium tetroxide	OsO_4	254.9		20	100	s			
Oxygen	O_2	32.00	0.00143		−183	0.041			
Palladious:									
Chloride	$PdCl_2$	177.62		Sublimes		s			s
Hydrate	$Pd(OH)_2$	140.73				i	i	i	s–alkalis
Iodide	PdI_2	359.91		300	Decomp.	i	i		
Nitrate	$Pd(NO_3)_2$	230.72				Decomp.			s
Sulphate	$PdSO_4 \cdot H_2O$	220.79		Decomp. at	Redness	Decomp.			s
Palladium	Pd	106.7	11.4						s–HNO_3
Perchloric acid	$HClO_4$	100.47	1.76	−35	19	s			
Phosphine	PH_3	34.09		−133	−85	l.s.		s	
Phosphoric:									
Acid	H_3PO_4	98.09	1.88	36.6	Decomp.	∞	∞		s
Anhydride	P_2O_5	142.08	2.39			Combines			s
Chloride	PCl_5	208.34		148	162	Decomp.	Decomp.	Decomp.	
Phosphorus	P_4	124.16	1.83	45	290	i	i	l.s.	s–CS_2
Acid	H_3PO_3	82.06		70	Decomp.	v.s.	v.s.		
Anhydride	P_2O_3	110.08	1.94	22.5	173	v.s.	v.s.		
Chloride	PCl_3	137.38	1.61	−112	78	Decomp.	Decomp.		
Red	P	31.04	2.1	250 changes		i	i		i–CS_2
Platinic chloride	$PtCl_4 \cdot 5H_2O$	427.12		Decomp.		v.s.	v.s.	v.s.	s
Platinous chloride	$PtCl_2$	266.12	5.87	Decomp.		i	i		s–HCl
Platinum	Pt	195.2	21.5	Oxyhyd.		i	i	i	s–*Aq. regia*
Plumbic:									
Acetate	$Pb(C_2H_3O_2)_2 \cdot 3H_2O$	379.20	2.5	200		2:3	2:1	s	s
Carbonate	$PbCO_3$	267.10	6.47			i	i	i	s
Chloride	$PbCl_2$	278.02	5.8	447	900	1:101	1:20	1:20	s
Chromate	$PbCrO_4$	323.10	6.0			i	i		s
Hydrate	$Pb(OH)_2$	241.12				l.s.	l.s.		s–alkalis
Oxide	PbO	223.10	9.21	Red heat		i	i		s–alkalis
Peroxide	PbO_2	239.10	9.45	Decomp.		i	i	i	
Phosphate	$Pb_3(PO_4)_2$	811.38	7.1			i	i		s–HNO_3

Sulphate........	[illegible]	[illegible]	[illegible]	[illegible]					H_2O_2
Sulphide.......	PbS	239.17	7.5	1015	1085	i	i	i	s–HNO_3
Potassium......	K	39.10	0.86	62.5	700	Decomp.	Decomp.	Decomp.	Decomp.
Acetate........	$K_2C_2H_3O_2$	137.22	....	292	....	s	8:1	s	s
Acid tartrate...	$HKH_4C_4O_6$	188.14	....	Decomp.	....	0.4:100	7:100	i	s
Alum.........	$K_2Al_2(SO_4)_4{\cdot}24H_2O$	948.84	1.73	84.5	....	1:10	36:10	....	....
Arsenate.......	K_3AsO_4	256.26	....	....	....	1:5	v.s.	4:100	....
Arsenite.......	K_2HAsO_3	202.17	....	....	....	v.s.	v.s.	....	....
Bicarbonate....	$KHCO_3$	100.11	....	Decomp.	....	1:4	1:1	1:1200	Decomp.
Bichromate....	$K_2Cr_2O_7$	294.2	2.69	400	Decomp.	1:10	1:1	i	s
Bromide.......	KBr	119.02	2.68	750	Sublimes	2:3	1:1	1:200	s
Carbonate.....	K_2CO_3	138.20	2.27	838	....	11:10	v.s.	i	Decomp.
Chlorate.......	$KClO_3$	122.56	2.32	334	Decomp. 400	1:14	1:2	1:120	Decomp.
Chloride.......	KCl	74.56	2.0	790	Sublimes	3:10	1:2	1:200	i–conc. HCl
Chromate......	K_2CrO_4	194.10	2.7	940	....	1:2	1:1.7	i	s
Chrome alum..	$K_2Cr_2(SO_4)_4{\cdot}24H_2O$	998.86	....	....	....	2:10	1:2	i	s
Cyanide.......	KCN	65.11	1.52	Red heat	....	v.s.	Decomp.	l.s.	s
Fluoride.......	$KF{\cdot}2H_2O$	94.13	2.45	....	....	v.s.	v.s.	l.s.	s
Ferricyanide...	$K_3Fe(CN)_6$	329.20	1.82	Decomp.	....	1:2.5	1:12	i	....
Ferrocyanide...	$K_4Fe(CN)_6{\cdot}3H_2O$	422.35	1.83	Decomp.	....	1:5[1]	1:1[1]	i	....
Hydrate.......	KOH	56.11	2.04	Red heat	Sublimes	2:1	v.s.	s	s
Iodate.........	KIO_3	214.02	3.97	560	....	8:100	....	....	....
Iodide.........	KI	166.02	3.06	639	....	14:10	2:1	1:7	s
Manganate....	K_2MnO_4	197.13	....	....	....	s	Decomp.	....	....
Nitrate........	KNO_3	101.11	2.08	340	Decomp.	1:3	2:1	i	s
Nitrite........	KNO_2	85.11	....	Red heat	....	3:1	v.s.	i	Decomp.
Oxalate........	$K_2C_2O_4{\cdot}H_2O$	184.21	....	....	....	s	s	....	s
Oxide.........	K_2O	95.10	2.56	....	....	v.s.	v.s.	v.s.	s
Permanganate .	$KMnO_4$	158.03	2.71	Decomp. 240	....	10:16	v.s.	Decomp.	s
Phosphate.....	K_2HPO_4	174.25	....	Decomp.	....	v.s.	v.s.	v.s.	s
Platinic chloride..........	K_2PtCl_6	486.16	3.99	Decomp.	....	1:100	1:19	v.l.s.	s
Pyroantimonate..........	$K_2Sb_2O_7$	430.60	....	....	....	l.s.	s	....	....
Silicate........	K_2SiO_3	154.5	....	890	....	s	s	....	Decomp.

THE PROPERTIES OF THE PRINCIPAL INORGANIC COMPOUNDS. *Continued*

Substance	Formula	Molecular weight O = 16	Specific gravity	Melting point, deg. C.	Boiling point, deg. C.	Solubility (parts solid to parts water)			
						Cold water	Hot water	Alcohol	Acids
Potassium:									
Sulphate	K_2SO_4	174.27	2.65	1070		1:8	1:4	i	s
Acid sulphate	$KHSO_4$	136.17	2.16	197	Decomp.	36:100	v.s.		s
Sulph-hydrate	KHS	72.17				s	s	s	Decomp.
Sulphide	K_2S	110.27				v.s.	v.s.	s	Decomp.
Sulphite	$K_2SO_3 \cdot 2H_2O$	194.30				1:1	v.s.	i	Decomp.
Tartrate	$K_2H_4C_4O_6$	226.13		Decomp.		15:10		0.4:100	s
Radium bromide	$RaBr_2$	386.24		728		s			
Realgar	As_2S_2	214.06	3.5			i	i		s–alkalis
Rubidium:									
Carbonate	Rb_2CO_3	230.90		Decomp. 740		v.s.			
Chloride	RbCl	120.91	2.2	710		84:100			
Sulphate	Rb_2SO_4	226.97	3.61			43:100			
Selenic acid	H_2SeO_4	145.22	2.95	58	260	v.s.			
Silicic acid	$Si(OH)_4$	96.33				l.s.			S–HF and alkalis.
Anhydride	SiO_2	60.3	2.7			i	i	i	s–HF and alkalis
Bromide	$SiBr_4$	347.98	2.8	13	153				
Chloride	$SiCl_4$	170.14	1.52	−89	59	Decomp.		Decomp.	
Fluoride	SiF_4	104.30		−140	−107	Decomp.	Decomp.		Decomp.
Hydride	SiH_4	32.33		Gas		i			
Iodide	SiI_4	535.98		120	290	Decomp.			
Sulphide	SiS_2	92.44				Decomp.		Decomp.	
Silicon	Si	28.3	2.49			i			
Silver	Ag	107.88	10.5			i	i	i	s–HNO_3
Arsenite	Ag_3AsO_3	446.60				i			
Bromide	AgBr	187.80	6.39	427	Decomp. 700	0.000008:100	i		s–conc. HCl
Chloride	AgCl	143.34	5.5	450		0.00015:	i		s–NH_4OH

Silver:									
Iodide	AgI	234.80	5.67	540	...	0.0000003 :100	i	...	i–NH_4OH
Nitrate	$AgNO_3$	169.89	4.35	224	Decomp. redness.	21:10	v.s.	...	s
Nitrite	$AgNO_2$	153.89	...	Decomp. redness.	...	1:120	Decomp.	...	...
Oxalate	$Ag_2C_2O_4$	303.76	...	Explodes	...	v.l.s.	v.l.s.	i	s–HNO_3
Oxide	Ag_2O	231.76	7.2	250 decomp	...	1:3000	...	...	s–HNO_3
Peroxide	Ag_2O_2	247.76	5.47	Decomp.	...	...	...	...	s–HNO_3
Phosphate	Ag_3PO_4	418.68	7.3	Redness	...	i	i	...	s–NH_4OH
Sulphate	Ag_2SO_4	311.83	5.41	654	Decomp.	1:150	1:88	...	s
Sulphide	Ag_2S	247.83	6.85	...	...	i	i	...	i–NH_4OH
Sulphite	Ag_2SO_3	295.83	...	Decomp.	...	l.s.	...	...	Decomp.
Sodium	Na	23.00	0.97	95	710	Decomp.	Decomp.	Decomp.	Decomp.
Acetate	$NaC_2H_3O_2 \cdot 3H_2O$	175.27	...	319	...	1:3	2:1	s	s
Ammon. phosphate	$NaNH_4HPO_4 \cdot 4H_2O$	209.15	1.55	Decomp.	...	16:100	1:1	i	s
Arsenate	$Na_2HAsO_4 \cdot 12H_2O$	402.16	...	...	...	1:3	v.s.	2:100	...
Arsenite	Na_2HAsO_3	169.97	...	...	...	v.s.	v.s.	...	...
Bicarbonate	$NaHCO_3$	84.01	2.2	Decomp. 270	...	0.1:10	Decomp.	i	Decomp.
Bichromate	$Na_2Cr_2O_7 \cdot 2H_2O$	298.03	...	...	...	7:4[1]	v.s.	...	s
Borate	$Na_2B_4O_7 \cdot 10H_2O$	382.16	1.69	Red heat	...	6:100	2:1	i	...
Bromide	$NaBr \cdot 4H_2O$	174.98	3.1	733	...	3:4[1]	112:100[1]	l.s.	...
Carbonate	$Na_2CO_3 \cdot 10H_2O$	286.16	1.45	...	...	21:100[1]	42:10[1]	i	Decomp.
Carbonate	Na_2CO_3	106.00	2.4–2.5	849	Decomp.	7:100	45:100	i	Decomp.
Chlorate	$NaClO_3$	106.46	...	Decomp.	...	1:1	2:1	s	Decomp.
Chloride	NaCl	58.46	2.13	776	White heat	1:3	4:10	i	i–conc. HCl
Chromate	$Na_2CrO_4 \cdot 10H_2O$	342.16	...	...	...	77:100[1]	s	...	s
Hydrate	NaOH	40.01	2.13	320	White heat	6:10	2:10	s	s
Hyposulphite	$Na_2S_2O_3 \cdot 5H_2O$	248.22	1.67	45	Decomp.	1:1	2:1	i	Decomp.
Iodide	$NaI \cdot 4H_2O$	221.96	2.45	650	...	18:10[1]	3:1[1]	s	...
Nitrate	$NaNO_3$	85.01	2.26	313	...	8:10	2:1	s	...
Nitrite	$NaNO_2$	69.01	...	271	...	8:10	v.s.	i	Decomp.
Oxide	Na_2O	62.00	2.8	...	...	v.s.	v.s.	s	s
Peroxide	Na_2O_2	78.00	2.8	Decomp.	...	Decomp.	Decomp.	...	s
Phosphate	$Na_2HPO_4 \cdot 12H_2O$	358.24	3.58	Decomp.[2]	...	1:25[1]	1:1[1]	i	s
Platinic chloride	$Na_2PtCl_6 \cdot 6H_2O$	562.06	...	Decomp.	...	v.s.	v.s.	s	s

THE PROPERTIES OF THE PRINCIPAL INORGANIC COMPOUNDS. *Continued*

Substance	Formula	Molecular weight O = 16	Specific gravity	Melting point, deg. C.	Boiling point, deg. C.	Solubility (parts solid to parts water) Cold water	Hot water	Alcohol	Acids
Sodium:									
Potass. tartrate	$NaKC_4H_4O_6·4H_2O$	281.51	1.79	75	220 decomp.				
Pyroantimon-						1:2	3:1	....	....
ate, hydrated	$Na_2Sb_2O_7·H_2O$	416.44	....	....	....	v.l.s.	v.l.s.	v.l.s.	....
Pyrophosphate	$Na_4P_2O_7·10H_2O$	399.24	....	77	....	6:100	9:10	i	s
Stannate	$Na_2SnO_3·4H_2O$	282.19	....	....	....	s	s	....	Decomp.
Silicate	Na_2SiO_3	122.30	....	1030	....	s	s	i	Decomp.
Sulphate	$Na_2SO_4·10H_2O$	322.23	1.49	Decomp.[1]	....	1:5[1]	1:2[1]	i	s
Sulphate	Na_2SO_4	119.07	2.67	884	....	v.s.	....	....	....
Sulphide	Na_2S	78.07	....	....	....	s	s	s	Decomp.
Sulphite	$Na_2SO_3·7H_2O$	252.18	1.56	Decomp.	....	1:4[1]	1:1[1]	i	Decomp.
Stannic:									
Chloride	$SnCl_4$	260.84	2.28	−33	114.1	Decomp.	....	....	s–HCl
Hydrate	H_2SnO_3	169.02	....	Decomp.	....	i	....	....	s–acids, alkalis.
Oxide	SnO_2	151.00	6.8	1130	....	i	....	....	i–acids
Sulphide	SnS_2	183.14	....	....	....	i	i	....	s–NH_4SH
Stannous:									
Chloride	$SnCl_2·2H_2O$	225.95	....	250	606	Decomp.	in excess	....	s
Hydrate	H_2SnO_2	153.02	....	Decomp.	....	i	i	....	s–acids, alkalis.
Oxychloride	$Sn_2OCl_2·2H_2O$	360.95	....	....	....	i	i	....	i
Oxide	SnO	135.00	6.1	Decomp.	....	i	i	....	s
Sulphide	SnS	51.07	4.97	970	1090	i	i	....	s–conc. HCl
Strontium	Sr	87.63	2.54	....	....	Decomp.	Decomp.	....	....
Bromide	$SrBr_2$	247.47	4.2	498	....	93:100	....	....	....
Carbonate	$SrCO_3$	147.63	3.6	Decomp. 1160	....	0.001:100	i	....	s–H_2CO_3
Chloride	$SrCl_2·6H_2O$	266.65	1.92	832	....	1:2[1]	1:1[1]	....	....
Hydrate	$Sr(OH)_2$	121.65	....	....	....	1:52	1:24	....	s
Nitrate	$Sr(NO_3)_2$	211.08	2.9	Decomp. 645	....	2:3	1:2	i	s
Oxide	SrO	103.63	3.9	3000	....	35:100	s	....	s

[1] Anhydrous form. melts at 860°. [2] Normal anhydrous phosphate melts at 957°C.

Strontium:									
Peroxide.......	SrO_2	119.63	5.46	Decomp.	....	Decomp.	....	....	....
Sulphate.......	$SrSO_4$	183.70	3.7	Decomp.	....	1:3000	1:3700	i	s–HCl
Sulphide.......	SrS	119.70	....	....	....	Decomp.	Decomp.	s	Decomp.
Sulphur:									
Allotropic......	S	32.07	1.98	....	....	i	i	....	i–CS_2
Common......	S	32.07	2.0	114	440	i	i	v.l.s.	s–CS_2
Sulphuretted hydrogen.......	H_2S	34.09	Liq. 0.9	−85	−63.5	305:100 vol.	....	....	....
Sulphuric:									
Acid..........	H_2SO_4	98.09	1.842	10.5	327	∞	∞	Decomp.	
Anhydride.....	SO_3	80.07	1.97	14.8	35	Combines	Combines	Decomp.	....
Chloride.......	SCl_2	102.99	1.62	Liquid	64 decomp.	Decomp.	....	....	....
Fuming acid...	$H_2S_2O_7$	178.16	1.9	Decomp.	....	∞	∞	Decomp.	....
Tetrachloride..	SCl_4	173.91	....	....	....	....	....	Decomp.	Decomp. H_2SO_4
Sulphurous:									
Acid..........	$H_2SO_3 + Aq$	....	....	....	....	s	....	....	....
Anhydride.....	SO_2	64.07	....	−76	−10	1:6 vols.	....	v.s.	....
Chloride.......	S_2Cl_2	135.06	1.68	Liquid	136	Decomp.	Decomp.	s	s–CS_2
Tantalum.......	Ta	181.5	10.78	....	....	....	....	....	i–H_2SO_4
Tantalic:									
Acid..........	$3Ta_2O_5 \cdot 5H_2O$	1419.08	....	....	....	....	....	....	s–alkalis
Anhydride.....	Ta_2O_5	443.0	7.28	....	....	....	....	....	i–acids
Chloride.......	$TaCl_5$	358.80	....	211	245	Decomp.	....	....	....
Fluoride.......	TaF_5	276.50	....	....	....	s	....	....	s–HF
Telluric:									
Acid..........	$H_2TeO_4 \cdot 2H_2O$	229.55	....	Decomp.	....	s	....	i	....
Anhydride.....	TeO_3	175.50	5.07	Decomp.	Decomp.	i	....	....	i
Tellurium.......	Te	127.5	6.25	500	Red heat	i	....	....	i–HCl
Tellurous:									
Acid..........	H_2TeO_3	177.52	....	....	....	l.s.	....	....	s
Anhydride.....	TeO_2	159.50	5.93	Dull red	Below 700	l.s.	....	....	s
Chloride.......	$TeCl_2$	198.42	....	175	327	Decomp.	....	....	....
Hydride.......	H_2Te	129.52	....	−48	0	s	....	....	....
Thallium.......	Tl	204.0	11.86	290	Red heat	i	....	....	s–HNO_3
Carbonate.....	Tl_2CO_3	264.00	7.1	272	Decomp.	4:100	....	....	....
Trichloride.....	$TlCl_3$	310.38	....	25	Decomp.	v.s.	....	....	....

THE PROPERTIES OF THE PRINCIPAL INORGANIC COMPOUNDS. *Continued*

Substance	Formula	Molecular weight O = 16	Specific gravity	Melting point, deg. C.	Boiling point, deg. C.	Solubility (parts solid to parts water)			
						Cold water	Hot water	Alcohol	Acids
Thallium:									
Ous oxide	Tl_2O	432.00		300		v.s.			
Sulphate	Tl_2SO_4	504.07	6.77	632	Decomp.	4.7:100			
Thorium:									
Nitrate	$Th(NO_3)_4 \cdot 12H_2O$	696.63				v.s.			
Oxide	ThO_2	264.4	9.87	Infus		i			
Tin, see Stannum	Sn	119.0	7.29	235	White heat	i	i	i	s–HCl
Titanic:									
Chloride	$TiCl_4$	189.94	1.76	−25	135	Decomp.	Decomp.		
Fluoride	TiF_4	124.1		Liquid		Decomp.			
Hydrate	$Ti(OH)_4$	112.13		Decomp.					s
Oxide	TiO_2	80.1	3.7–4.2	1500		i	i		i
Sulphide	TiS_2	112.24				Decomp.			
Titanium	Ti	48.1				Decomp.			s–HCl
Titanous:									
Chloride	Ti_2Cl_6	308.96			Red heat	s			s
Oxide	Ti_2O_3	144.20							s–H_2SO_4
Tungsten	W	184.0	1.92						
Hexachloride	WCl_6	396.76		275	347	i			
Tungstic:									
Acid	H_2WO_4	250.02				i			s–alkalis
Anhydride	WO_3	232.00	7.2	Red heat		i			s–alkalis
Uranium	U	238.5	18.4			i	i		s
Uranous:									
Chloride	UCl_4	380.34		Decomp.		s			
Dioxide	UO_2	270.5	10.9	Oxidizes		i	i	i	s–conc. acids
Uranyl:									
Bromide	UO_2Br_2	430.34				s			s
Chloride	UO_2Cl_2	341.42		Red heat	Decomp.	s	s	s	s–ether
Fluoride	UO_2F_2	308.5				s	s	s	
Oxide	UO_3	286.5	5.1	Decomp.					

Uranyl:									
Nitrate	$UO_2(NO_3)_2 \cdot 6H_2O$	502.62	2.81	59.5	118	13:10[1]			s
Sulphate	$UO_2(SO_4)_2 \cdot 3H_2O$	516.69							s–H_2SO_4
Sulphide	UO_2S	302.57				l.s.			
Uranic oxide	U_3O_8	605.00	7.3	Decomp.					
Vanadium	V	51.0	5.5			i			s–conc. H_2SO_4.
Pentoxide	V_2O_5	182.0	3.35	658		1:1000			s–H_2SO_4
Vanadic acid	HVO_3	100.01				l.s.			s–alkalis
Zinc	Zn	65.37	6.9	433	1040	i	i	i	s
Bromide	$ZnBr_2$	225.21		Sublimes		s	s	s	s
Carbonate	$ZnCO_3$	125.37	4.42	Decomp. 300		0.001:100	i		s
Chloride	$ZnCl_2$	136.29	2.91	262	730	37:10	v.s.		s
Chromate	$Zn_2(OH)_2CrO_4 \cdot H_2O$	298.77				i	i		s
Ferrocyanide	$Zn_2Fe(CN)_6$	342.64				i			i–HCl
Hydrate	$Zn(OH)_2$	99.39		Decomp.		i	i		s–alkalis
Iodide	ZnI_2	319.01				v.s.	v.s.		s
Nitrate	$Zn(NO_3)_2 \cdot 6H_2O$	297.49		Decomp.		115:100[1]	v.s.	s	s
Oxide	ZnO	81.37	5.6			i	i	i	s
Phosphide	Zn_3P_2	258.89		Red heat					
Sulphate	$ZnSO_4 \cdot 7H_2O$	287.55	1.95	Decomp.		135:100	655:100		s
Sulphide	ZnS	97.44	3.5–4.2	1050		i	i		s
Zirconium	Zr	90.6	4.15			i	i		s–HF
Bromide	$ZrBr_4$	410.28		Sublimes	ed heat	Decomp.			
Chloride	$ZrCl_4$	232.44		Sublimes	readily	v.s.			
Fluoride	$ZrF_4 \cdot 3H_2O$	220.65				s			s
Nitrate	$Zr(NO_3)_4$	338.64				s			s
Oxide	ZrO_2	122.60	5.71	Infus		i	i		l.s.
Silicate	$ZrSiO_4$	182.90							
Sulphate	$ZrSO_4$	186.67		Decomp. at red.		s	v.s.		s

[1] The molecular weights have been recalculated by the 1915 atomic weight table on a basis of O = 16. Where a melting point greatly exceeding 100°C. is given for a hydrated salt, the melting point is that of the anhydrous form.

Magnetic Susceptibilities of the Elements[1]

h = magnetic force.
I = intensity of magnetization.
= magnetic moment per cm.^{3}
= pole strength per cm.^{2}
B = magnetic induction, or flux density = $h + 4\pi I$.

B, h and I are in lines per cm.^{2} and are vector quantities. Unit: 4π lines start from a unit magnetic pole.

μ = permeability = B/h.

H = susceptivity = $I/h = \frac{\mu - 1}{4\pi}$.

Coercivity, $h_{B=0}$, is the demagnetizing force required to make $B = 0$ after saturation.

Coercive force is the demagnetizing force required to make $B = 0$ after some particular field strength.

Remanence, $B_{H=0}$, is the induction remaining when the magnetizing force is removed after saturation.

The work done, *i.e.*, hysteresis loss, Qe, in taking a cm.^{3} of magnetic material through a magnetic cycle between the limits

$$+H_e \text{ and } -H_e = \int_{-H_e}^{+H_e} hdI = \tfrac{1}{4}\pi \int_{-H_e}^{+H_e} hdB.$$

STEINMETZ's empirical formula for the hysteresis loss is ηB^n_{max}, where η is a constant and $\eta = 1.6$ (usually). The magnetic properties of a material depend not only on its chemical composition, but on its previous mechanical and heat treatment; thus only general characteristics are indicated below.

Good permanent magnet steel contains about 0.5 per cent. W and 0.6 per cent. C. Cast iron, chilled from 1000°C., may also be used, but the results will never be so good as with steel. The HEUSLER alloys (Cu, Mn, Al) are remarkable in showing high magnetism when the components do not.

PERMEABILITY μ

Material	$h = 0.5$	$h = 1$	$h = 5$	$h = 20$	$h = 60$	$h = 150$
Swedish wrought iron....	2500	3710	2060	736	274	120
Annealed cast steel......	1450	3500	2100	747	280	123
Unannealed cast steel....	490	970	1700	680	270	122
Cast iron.............	....	......	81	182	117	65
Magnet steel { hardened.	....	......	68[2]	78	193	100
Magnet steel { tungsten..	....	......	80[3]	119	204	100

The figures given are only roughly comparative and can only be used as a general working guide. If exact results on particular specimens are wanted, laboratory determinations are necessary.

[1] KAYE and LABY, "Physical and Chemical Constants."
[2] At $h = 15$.
[3] At $h = 10$.

Material	Coercivity	Remanence	H_e	Hysteresis loss Qe, ergs/cm.[3]
Swedish wrought iron	0.8	4,000	200	6,700
Annealed cast steel	0.97	7,100	151	11,700
Unannealed cast steel	2.08	9,000	156	20,400
Cast iron	11.9	4,230	155	34,300
Magnet steel, hardened	52.6	11,700	234	211,000
Magnet steel, tungsten	27.5	9,880	505	116,000

The figures given are only roughly comparative and can only be used as a general working guide. If exact results on particular specimens are wanted, laboratory determinations are necessary.

Material	h_{max}	Induction, B, for		μ_{max}	For h_{max}		
		h_{max}	h = 100		Coer.	Reman.	Hyst. loss, ergs/cm.[3]
Mild steel	129	18,190	17,700	8,350	0.6	10,300	4,900
Steel, 2.8% Cr, 0.8% C.	....	....	....	....	56.0	6,400[2]	....
Steel, 5.5% W, 0.6% C; hardened at 770°	....	....	....	....	72.0	7,000[2]	280,000
Steel, 7.7% W, 1.9% C; hardened at 800°	....	....	....	....	85.0	4,700[2]	....
Steel, 4% Mo, 1.2% C; hardened at 800°	....	....	....	....	85.0	6,700	....
Iron	50	17,100	....	1,750	2.2[1]	53% B_{max}	....
Silicon iron, 0.6% Si,	55	16,000	....	1,900	1.6[1]	43% B_{max}	....
Silicon iron, 4.5% Si,	56	15,100	....	2,500	1.2[1]	39% B_{max}	....
Electrolytic iron	210	21,250	....	....	18.0	10,000	....
Electrolytic iron heated to 1200° C.	....	....	16,000	....	2.5	12,500	....
HADFIELD's Mn steel[3]	....	....	....	1.3–1.5	....	Small	....
Nickel, annealed	100	5,137	....	296	8.0	3,570	....
Cobalt	140	10,000	9,500	174	12.0	3,400	....
Cobalt, 96%	114	8,237	7,800	177	....	....	19,000
HEUSLER alloy[4]	92	2,735	....	115	....	....	....

The figures given are only roughly comparative and can only be used as a general working guide. If exact results on particular specimens are wanted, laboratory determinations are necessary.

$$H = I/h = \frac{\mu - 1}{4\pi}, \quad H = 0 \text{ for a vacuum.}$$

The susceptibility depends very much upon the purity of the material, especially upon the absence of iron. It appears to be a periodic property of the atomic weight.

[1] $H = 10$.
[2] Bar magnet.
[3] 12 per cent. Mn, 1 per cent. C.
[4] Mn 24, Al 16, Cu 60.
An alloy of iron and boron Fe_2B is highly magnetic, as is also MnB (16.66 per cent. B). "Trans. VIII Int. Cong. App. Chem."

Elem. solids	$H \times 10^{-6}$	Elem. solids	$H \times 10^{-6}$	Elem. solids	$H \times 10^{-6}$
Al[2]	+ 0.65	P	− 0.9	U	+ 0.9[1]
Sb	− 0.95	Pt	+ 1.32	V	+ 1.5
As	− 0.31	K	+ 0.4	Zn	− 0.15
Bi	− 1.4	Rh	+ 1.1	Zr	− 0.45
B	− 0.71	Ru	+ 0.56	Liquids:	
Cd	− 0.17	Se	− 0.32	Br	− 0.41
Cr	+ 3.7	Si	− 0.12	Hg	− 0.19
Cb	+ 1.3(?)	Ag	− 0.2	N (liq.)	+ 0.28
Cu	− 0.087	Na	+ 0.51	O (liq.)	+ 0.324
Au	− 0.15	S	− 0.5	H_2O (15°)	− 0.80
I	− 0.36	Ta	+ 0.93	Gases:	
Ir	+ 0.15	Te	− 0.32	Air (16°)	+ 0.032
Fe	see p. 229	Tl	− 0.3[1]	A	− 0.010
Pb	− 0.12	Th	+ 1.8	He	− 0.002
Mg	+ 0.55	Sn	+ 0.025	H	− 0.008
Mn	+ 10.6(?)	Ti	+ 2.0[1]	N	+ 0.024
Mo	+ 0.04(?)	W	+ 0.33	O	+ 0.123

The figures given are only roughly comparative and can only be used as a general working guide. If exact results on particular specimens are wanted, laboratory determinations are necessary.

There is a critical temperature above which magnetic permeability is very small; in the case of iron it is one of the recalescence temperatures. The critical temperature is not perfectly definite, but depends upon whether the material is being heated or cooled.

Fe, 690–895°C.; Ni, 95 per cent., 300–377°C.; magnetite, 582°C.; magnetite, 582°C.; HEUSLER alloys, about 300°C.; Co, 1102°C.; Cu, 72°C.; Zn, 300–350°C, possibly also at 170°C.; Sn, 18° and 161°C.

Electromagnetic Separation

MAGNETIC PERMEABILITY

Iron	100,000	Oxide of manganese	167
Magnetite	40,000	Black oxide of nickel	106
Spathic iron ore	767	Manganese sulphate	100
Hematite	714	Ferrous sulphate	78
Oolitic iron ore	593	Nickelous oxide	35
Limonite	296		

The figures given are only roughly comparative and can only be used as a general working guide. If exact results on particular specimens are wanted, laboratory determinations are necessary.

Magnetic Permeability (in descending scale).
FARADAY'S arrangement.
Paramagnetic: Fe, Ni, Co, Mn, Cr, Ti, Pd, Pt, Os.
Diamagnetic: Bi, Sb, Zn, Sn, Cd, Hg, Pb, Ag, Cu, As, U, Ir, W.
Iron = 2000; air = 1; Bi = 0.998.

[1] Approximate only.
[2] Probably this paramagnetism is due to contained iron, for the more nearly chemically pure Al becomes the less its magnetism. This value is given by HORDA, *Annalen der Physik*, 1910, p. 1045.

Action of the Wetherill Magnet on Minerals Found in Placer Sands, Together with Their Specific Gravity[1]

Non-magnetic	Sp. gr.	Separated by current of ½ amp. or less	Separated by current of 2 amp.	Separated by current of 3½ amp.
Mineral:				
Iridium	22.0	...	...	...
Iridosmium	19.0	...	...	...
Gold	15.6–19.3	...	...	...
Platinum	14–19	Platinum[2]	Platinum[2]	Platinum[2]
Amalgam	14.0	...	...	...
Mercury	13.5	...	...	...
Lead	11.0	...	...	...
Cinnabar	8.1	...	...	...
Galena	7.5	...	...	...
Wolframite	7.2–7.5	Cast iron 7.5	...	...
Cassiterite	7.0	Josephinite 7	...	Cassiterite 7
Scheelite	6.0	...	Hematite 5	...
Crocoite	6.0	...	...	...
Columbite	5.3–7.3	...	...	...
Pyrite	5.0	Magnetite 5.2	Ilmenite 5	Monazite 5
Molybdenite	4.8	...	...	...
Zircon	4.7	...	...	...
Barite	4.3–4.6	...	Chromite 4.3–4.6	Pyrrhotite 4.5
Corundum	4.0	...	Rutile 4.2	Corundum 4
Cyanite	3.6	...	Limonite 4	Brookite 4
Diamond	3.5	...	Garnet 3–4	...
Topaz	3.5	...	Pyroxene 3.2–3.6	...
Fluorite	3.25	...	Epidote 3.5	Spinel 3.5–4
Apatite	3.2	...	Titanite 3.5	...
Spodumene	3.1	...	...	...
Beryl	2.7	...	Chrysolite 3.3	...
			Tourmaline 3	...
			Siderite 3	...
			Serpentine 2.5	...

Minerals Which Become Quite Magnetic on Roasting[3]

Sulphides oxidizing roast without carbon		Oxides and carbonates reducing roast with carbon	
Pyrite,	FeS_2	Hematite,	Fe_2O_3
Marcasite,	FeS_2	Siderite,	$FeCO_3$
Chalcopyrite,	$FeCuS_2$	Wolframite,	$FeMnWO_4$
Bornite,	$FeCu_3S_3$	Chromite,	$FeCr_2O_4$
Arsenopyrite,	$FeAsS$		

Zinc-Iron Separation by Magnetic Separators Tomboy Gold Mines, Telluride, Colo.[4]

	Au, oz.	As, oz.	Pb, per cent.	Zn, per cent.	Fe, per cent.	Cu, per cent.	SiO_2, per cent.
Zinc concentrates	0.80	4.00	4.10	45.70	6.20	1.90	13.40
Iron concentrates	0.75	6.74	5.14	12.00	40.00	7.00	12.30

[1] R. H. Richards, "Ore Dressing," Vol. IV.
[2] Probably due to iron.
[3] R. H. Richards, "Ore Dressing," Vol. II.
[4] R. H. Richards, "Ore Dressing," Vol. IV.

Shrinkage of Metals[1]

Metal	Casting temperature, deg. C.	Freezing point, deg. C.	Shrinkage during freezing, per cent.	Total shrinkage, per cent.
Pb	500	326	0.065	0.82
Pb	600	326	0.065	0.83
Zn	650	416	0.08	1.40
Zn	700	416	0.08	1.40
Zn	750	416	0.08	1.40
Sn (Banca)	550	225	0.1–0.15	0.44
Sn	500	225	0.1–0.15	0.55
Al	800	683	....	1.78
Al	850	683	....	1.78
Cu	1250	1060	Expansion	1.42
Bi	500	261	....	0.29
Sb	710	621	....	0.29
Sb	750	621	....	0.63
Sb	800	621	....	0.29
Sb	1050	621	....	0.66
Na[2]	....	....	....	2.57

The expansion of copper is to be attributed to the setting free of dissolved gas. The lead, zinc, copper and antimony that Wüst worked with were not even commercially pure. This may account for the inconsistency of his results with those of other authorities, given below.

Shrinkage of Metals[3]

Metals	Percentage increase of volume on melting
Sodium	2.5 (*a*)
	2.5 (*b*)
Potassium	2.5 (*a*)
	2.6 (*b*)
Tin	2.8 (*a*)
	2.8 (*c*)
Cadmium	5.2 (*a*)
	4.72 (*c*)
Lead	3.7 (*a*)
	3.39 (*c*)
Thallium	3.1 (*a*)
Zinc	0.9 (*a*)
Aluminum	4.8 (*a*)
Tellurium	7.3 (*a*)
Antimony	1.4 (*a*)
Bismuth	−3.27 (*a*)
	−3.31 (*c*)
	−3.0 (*d*)

(*a*) M. Toepler, *Annalen der Physik*, 1888, Vol. 34, p. 21.
(*b*) H. Block, *Zeit. für Phys. Chem.*, 1912, Vol. 78, p. 385.
(*c*) G. Vincentini and D. Omodei, *Atti R. Accademia delle Scienze di Torino*, 1889, Vol. 31, p. 25.
(*d*) C. Ludeking, *Annalen der Physik*, 1888, Vol. 34, p. 21.

[1] From Hofman's "General Metallurgy," originally from Wüst, *Metallurgie*, Vol. 6, 1909, p. 769.
[2] *Chem. Trade Journ.*, June 26, 1915.
[3] Compilation in *Engineering*, Apr. 3, 1914, p. 473.

SECTION IV

CHEMICAL DATA

FUNDAMENTAL CHEMICAL LAWS

Avogadro's.—Equal volumes of all gases and vapors contain the same number of ultimate particles or molecules at the same temperature and pressure.

Conservation of Energy.—Whenever a change in mode of manifestation of energy takes place, the total amount of energy remains a constant.

Dalton's.—See multiple proportions.

Definite Proportions.—A chemical compound always contains the same constituents in the same proportion by weight.

Diffusion of Gases.—The rate of diffusion of gases is approximately inversely proportional to the square roots of their specific gravities.

Dulong and Petit.—The product of the atomic weight and the specific heat of the same element is a constant.

Gay-Lussac's.—When gases or vapors react on each other the volumes both of the factors and the products of the reaction always bear to each other some simple numerical ratio.

Indestructibility of Matter (Lavoisier).—Whenever a change in the composition of substances takes place, the amount of matter after the change is the same as before the change.

Mariotte's.—The volume of a gas is directly proportional to the absolute temperature and inversely proportional to the absolute pressure upon it.

Multiple Proportions (Dalton).—If two elements *A* and *B* form several compounds with each other, and we consider any fixed mass of *A*, then the different masses of *B* which combine with the fixed mass *A* bear a simple ratio to one another.

Periodic.—The properties of an element are periodic functions of the atomic weight.

The Periodic Table

The so-called "periodic law" was the enunciation by MENDELEEF that the atomic weight of any element determines its properties, or, that the properties of the elements are periodic functions of the atomic weight. Roughly, if the elements are arranged in recurring "octaves" according to increasing atomic weights, elements of similar properties fall in columns. While this is so generally true that MENDELEEF was enabled to prophesy the discovery of certain elements with certain properties,

it is not without its exceptions, if our present knowledge be correct. For instance, according to atomic weight, iodine should come before tellurium, while according to its properties it comes after it. Argon and potassium form another such exceptional case.

The table following (p. 238), gives the places of most of the common elements, but omits most of the radioactive elements and the rare earths. These latter are, Pr, 140.6; Nd, 144.3; Sa, 150.4; Eu, 150.0; Gd, 157.3; Tb, 159.2; Ho, 163.5; Ds, 162.5; Er, 167.4; Tm, 168.5 [2 modifications (?)]; Lu, 174.0.

As to the radioactive elements, these are, as is well known, characterized by a greater or less instability. After a certain period of existence,[1] which may range from over a thousand million years, as in the case of uranium (U_1) to a millionth of a second as in the case of radium (RaC_1) the atom disintegrates spontaneously and yields an atom which possesses totally distinct properties. The disintegration is detected by the expulsion either of alpha or of beta particles.[2] Accompanying the expulsion of beta particles there is also observed in a number of cases, an emission of gamma rays. These are electromagnetic pulses of extremely short wave length (about 10^{-9} cm.) and are probably due to the bombardment of the atoms of the radioactive substance itself by the beta particles.

As a result of the large amount of careful work which has been carried out during the past few years in investigating the relationship between the different radioactive elements and their transformation products, it has been concluded that there exist three well-defined disintegration series whose starting points are uranium, thorium, and actinium, respectively.

Fig. 1 illustrates diagrammatically the manner in which the members of these series appear to be related.

When mesothorium 11 disintegrates, it yields radiothorium and as a beta particle is expelled during the transformation there is no change in atomic weight. Radiothorium is chemically allied to thorium and non-separable from it. These facts lead to the conclusion that radiothorium belongs to Group 1V and mesothorium 11 must therefore belong to Group 111.

Passing to thorium X, we here again come to an element which is chemically similar to radium, thus placing it in Group 11. The atom of thorium X expels an alpha particle and yields thorium emanation, a *gas* which is *inert chemically*, and condenses at low pressures between $-120°$C. and $-150°$C. The emanation resembles, therefore, the rare gases of the argon group.

Thorium emanation is the first member of the group of transformation products that constitute the thorium "active deposit." They are indicated in Fig. 1 as thorium A, B, C_1, C_2 and D.

[1] From the *General Electric Review*, July, 1915.

[2] The alpha particle has the same mass as an atom of helium, but differs from the latter in possessing two unit positive charges, 2E = 9.54 × 10 E.S.U. The beta particles correspond in mass and electric charge to the electrons units of negative electricity, E = 4.77 × 10 E.S.U.

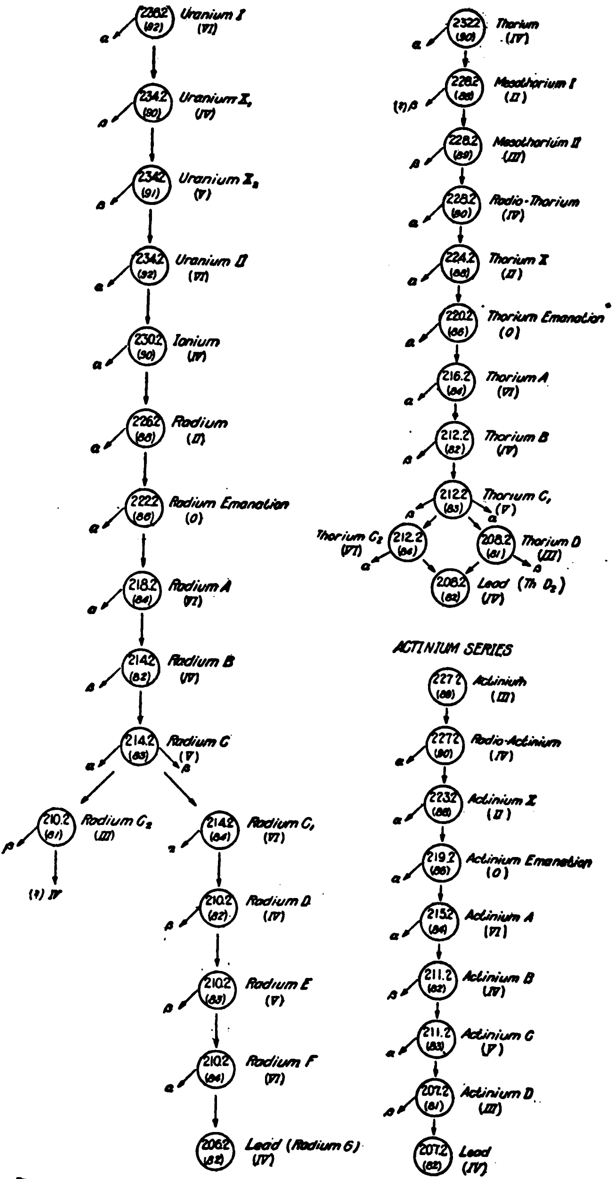


FIG. 1.—Method of disintegration of radioactive elements. (235)

The diagrams illustrating the actinium and uranium series are self-explanatory. In a general way the three series are quite similar. The most noteworthy feature about these radioactive elements is the fact that individual members of each series appear to be chemically indistinguishable from certain members of the other series. Thus thorium *B* and radium *B* possess identical chemical properties. If it were not for the difference in period of existence of both substances it would be impossible to differentiate them.

Isotopes.—SODDY first drew attention to this and similar cases of radioactive elements that are chemically identical and since they must occupy the same place in the Periodic Table he has designated them *isotopes*. Thus the elements uranium X_1, ionium, and radioactinium are isotopic. A similar example is furnished by the three emanations, and by radium and thorium *X*. A remarkable feature about these isotopes is that although they are chemically the same, they differ in atomic weights. In other words, we have here cases of elements that are absolutely inseparable by all chemical methods so far devised, and yet differ in that respect which has hitherto been taken to be the most important characteristic of an element—its atomic weight.

Soddy's Law of Sequence of Changes.—A comprehensive survey of the chemical properties of the different radioactive elements has led SODDY and FAJANS independently to an interesting and extremely important generalization which enables them to assign these isotopes to their places in the Periodic Table.

It will be remembered that an alpha particle is a helium atom with two positive charges. By its expulsion, therefore, the atom must lose two positive charges, and the atomic weight must decrease by four units. Similarly, the expulsion of a beta particle means the loss of a negative charge or, what is equivalent, the gain of one positive charge; and since the mass of the beta particle is extremely small compared with that of the atom, there is practically no decrease in atomic weight. Now in the Periodic Table the valency for oxygen, an electronegative element, increases regularly as we pass from Group 0 to Group VIII, while that for hydrogen, an electropositive element, decreases, *i.e.*, the electropositive characteristic increases by one unit for each change in the group number as we pass in any series from left to right. Furthermore, in each group the electropositive character increases regularly with increasing atomic weight.

These considerations led SODDY and FAJANS to this conclusion: *The expulsion of an alpha particle from any radioactive element leads to an element which is two places lower in the Periodic Table* (and has an atomic weight which is four units less) *while the emission of a beta particle leads to an element which is one place higher up*, but has the same atomic weight.

It is possible, therefore, to have elements of the same atomic weight but possessing distinctly different chemical properties,

and, on the other hand, since the effect of the emission of one alpha particle may be neutralized by the subsequent emission of two beta particles, it is possible to have two elements which differ in atomic weight by four units (or some multiple of four) and yet exhibit chemically similar properties.

As an illustration, let us consider the Uranium Series. Uranium 1 belongs to Group VI. By the expulsion of an alpha particle we obtain uranium X_1, an element of Group IV. This atom in turn disintegrates with the expulsion of a beta particle. Consequently uranium X_2 must belong to Group V. In this manner we can follow the individual changes that lead to the different members of the series, and by means of the generalization of SODDY and FAJANS we cannot only assign to each element its place in the Periodic Table but also its atomic weight, as has been done in Fig. 1.

This generalization has been of material assistance in elucidating some of the difficult problems in the study of the disintegration series. More than this, it has led to the intensely interesting conclusion that the end product of each of the three radioactive series in an isotope of lead. The results of the most recent work on the atomic weight of lead are in splendid accord with this deduction, as it has been found that lead which is of radioactive origin, has a slightly lower atomic weight than ordinary lead.[1]

In a couple of cases the isotope has not been definitely isolated, but there can hardly be any doubt of its existence. Thus, the disintegration product of radium C_2 must be an element of Group IV, but the evidence for its existence is very meager.

[1] *J. Am. Chem. Soc.*, 36, 1329, 1914.

THE PERIODIC TABLE OF THE ELEMENTS

Series	Zero group	Group I R_2O	Group II RO	Group III R_2O_3	Group IV RH_4 RO_2
1		H = 1.008	....	....	....
2	He = 4.0	Li = 6.94	Be = 9.1	B = 11	C = 12
3	Ne = 20.0	Na = 23.0	Mg = 24.32	Al = 27.1	Si = 28.3
4	Ar = 39.88	K = 39.1	Ca = 40.07	Sc = 44.1	Ti = 48.1
5	....	(Cu) = 63.57	Zn = 65.37	Ga = 69.9	Ge = 72.5
6	Kr = 82.92	Rb = 85.45	Sr = 87.63	Yt = 88.7	Zr = 90.6
7	....	(Ag) = 107.9	Cd = 112.4	In = 114.8	Sn = 119
8	Xe = 130.2	Cs = 132.8	Ba = 137.37	La = 139.0	Ce = 140.25
9	....	(−)	....	....	....
10	....	....	....	Yb = 173.2	....
11	....	(Au) = 197.2	Hg = 200.6	Tl = 204.0	Pb = 207.1
12	....	....	Ra = 226.2	....	Th = 232.4

Series	Group V RH_3 R_2O_5	Group VI RH_2 RO_3	Group VII RH, R_2O_7	Group VIII RO_4
1	....	....	....	....
2	N = 14.01	O = 16.0	F = 19.0	....
3	P = 31.04	S = 32.07	Cl = 35.46	....
4	V = 51.0	Cr = 52.0	Mn = 54.93	Fe = 55.84, Ni = 58.68 Co = 58.97, Cu = 63.57
5	As = 74.96	Se = 79.2	Br = 79.92	....
6	Cb = 93.5	Mo = 96.0	= 100.0	Rh = 102.9, Ru = 101.7 Pd = 106.7, Ag = 107.88
7	Sb = 120.2	Te = 127.5	I = 126.92	....
8	....	....	....	....
9	....	....	....	....
10	Ta = 181.5	W = 184.0	....	Ir = 193.1, Pt = 195.2 Os = 190.9, Au = 196.7
11	Bi = 208.0	....	....	....
12	....	U = 238.5	....	....

Examples of the manner in which the properties of the elements are progressive functions of the atomic weight are shown in the tables of the Ca-Sr-Ba, and Fl-Cl-Br-I families which follow:

Element	Calcium	Strontium	Barium	
Atomic mass.....	40	88	137	
Specific gravity...	1.6	2.5	3.6	
Carbonate dissociates; temperature...........	600C.	1100°C.	1400°C.	
Grams of hydroxide soluble in a liter of water at 15°C..........	1.32	18	50	
Heat of formation of chloride; units.	170	185	195	

Element	Fluorine	Chlorine	Bromine	Iodine
Atomic mass.....	19	35.5	80	127
Boiling temperature...........	−187°C	−33°	59°	184°
Specific gravity	1.15 (liquid)	1.5 (liquid)	3.2 (liquid)	5 (solid)
Union with hydrogen takes place.	In the dark at ordinary temperatures.	In sunlight.	At red heat.	At red heat but incompletely.
Heat of formation of hydrogen compound.	37.6 heat units.	22	8	−6.1
Stability of hydrogen compound	Most stable.	Decomposed at 1500°C.	Decomposed at 800°C.	Decomposed at 180°C.

ELECTROCHEMICAL EQUIVALENTS[1]

Element	Valence	Atomic weight	Electrochemical equivalent (1 amp. 1 sec.)
Al +........	3	27.1	0.00009363
Ag +........	1	107.88	0.0011183
Br −........	1	79.92	0.00082845
Cd +........	2	112.40	0.00058257
Ca +........	2	40.0	0.00020732
Cl −........	1	35.46	0.00036758
Co +........	2	58.97	0.00030564
Cu +........	2	63.57	0.00032948
Cu +........	1	63.57	0.00065897
Sn +........	2	119.0	0.00061678
Sn +........	4	119.0	0.00030839
Fe +........	2	55.84	0.00028947
Fe +........	3	55.84	0.00019267
F −........	1	19.0	0.00019695
H +........	1	1.008	0.000010449
I −........	1	126.92	0.00131566
Hg +........	2	200.6	0.00103661
Hg +........	1	200.6	0.00207322
Ni +........	2	58.68	0.00030414
Au +........	3	197.2	0.00068139
O −........	2	16.00	0.000082928
Pt +........	4	195.2	0.00050584
Pt +........	2	195.2	0.00101168
Pb +........	2	207.1	0.00107340
K +........	1	39.10	0.00040531
Na +........	1	23.00	0.00023842
Zn +........	2	65.37	0.00033881
Sb +........	3	120.2	0.00041532
Li +........	1	6.94	0.00007245
Mg +........	2	24.32	0.00011567
Mn +........	3	54.93	0.0001891
Si −........	2	28.3	0.0001449
S −........	2	32.07	0.0001656

[1] GORE, "The Art of Electrolytic Separation of the Metals."

International Atomic Weights, 1915

Element	Symbol	Weight	Valence[1]	Electrochem. equivalents, g. per amp.-hr.	Melting points	Boiling points
Aluminum..	Al	27.1	3	0.3368	658.7	1800.0
Antimony...	Sb	120.2	3	1.4966	630.0	1460.0
Argon......	A	39.88	0	....	−188.0	−186.0
Arsenic.....	As	74.96	3	0.9324	850.0	450.0[2]
Barium.....	Ba	137.37	2	2.5619	850.0	....
Bismuth....	Bi	208.0	3	2.5854	271.0	1440.0
Boron......	B	11.0	3	....	2350.0	....
Bromine....	Br	79.92	1	2.9814	−7.3	58.75
Cadmium...	Cd	112.40	2	2.0955	320.9	778.0
Caesium....	Cs	132.81	1	....	26.0	....
Calcium....	Ca	40.07	2	0.7477	810.0	....
Carbon.....	C	12.00	4	0.1118	>3600.0	....
Cerium.....	Ce	140.25	4	....	623.0	....
Chlorine....	Cl	35.46	1	1.3220	−101.5	−37.6
Chromium..	Cr	52.0	3	0.6476	1520 to >Fe	2200.0
Cobalt......	Co	58.97	2	1.1000	1478 ± 5	....
Columbium.	Cb	93.5	5	....	1950–2200	....
Copper.....	Cu	63.57	2	1.1858	1083.0	2100.0
Dysprosium.	Dy	162.5	......	....	....	....
Erbium.....	Er	167.7	......	....	....	....
Europium...	Eu	152.0	......	....	....	....
Fluorine....	F	19.0	1	0.7085	−223.0	−187.0
Gadolinium.	Gd	157.3	......	....	....	....
Gallium.....	Ga	69.9	......	....	30.1	....
Germanium	Ge	72.5	......	....	958.0	....
Glucinum...	Gl	9.1	......	....	1800.0	....
Gold.......	Au	197.2	3	2.4513	1063.0	....
Helium.....	He	4.002	0	....	−271.9	−268.8
Holmium...	Ho	163.5	......	....	....	....
Hydrogen...	H	1.008	1	0.03759	−259.0	−252.8
Indium.....	In	114.8	......	....	154.5	....
Iodine......	I	126.92	1	4.7303	114.0	184.35
Iridium.....	Ir	193.1	4	....	2300.0	....
Iron........	Fe	55.84	2	1.0404	1530 ± 5	2450.0
Krypton....	Kr	82.92	......	....	−169.0	−151.7
Lanthanum.	La	139.0	......	....	810.0	....
Lead.......	Pb	207.20	2	3.8613	327.4	1525.0
Lithium.....	Li	6.94	1	0.2622	186.0	....
Lutecium...	Lu	175.0	......	....	....	....
Magnesium.	Mg	24.32	2	0.4531	651.0	1120.0
Manganese.	Mn	54.93	2	1.0255	1260 ± 20	1900.0
Mercury....	Hg	200.6	2	7.4803	−38.7	357.0
Molybdenum......	Mo	96.0	2	1.7900	2500.0	....
Neodymium	Nd	144.3	......	....	840.0	....
Neon.......	Ne	20.0	0	....	−253.0	....

[1] In those cases in which a metal has two valences, the valence given corresponds to the electrochemical equivalent, and may not necessarily be the commoner one.

[2] Sublimes.

INTERNATIONAL ATOMIC WEIGHTS, 1915. *Continued*

Element	Symbol	Weight	Valence[1]	Electrochem. equivalents, g. per amp.-hr.	Melting points	Boiling points
Nickel......	Ni	58.68	2	1.0945	1452 ± 3	....
Niton......	Nt	222.4	0	....	....	....
Nitrogen....	N	14.01	3	0.1745	−210.5	−195.7
Osmium....	Os	190.9	......	....	2700.0	....
Oxygen.....	O	16.00	2	0.2983	−218.0	−183.0
Palladium ..	Pd	106.7	2	1.9951	1550.0	....
Phosphorus.	P	31.04	......	....	44.1	287.0
Platinum...	Pt	195.2	4	1.8206	1755.0	....
Potassium ..	K	39.10	1	1.4584	62.3	667.0
Praseodymium.....	Pr	140.9	......	....	940.0	....
Radium.....	Ra	226.0	2	....	900.0	....
Rhodium...	Rh	102.9	......	....	1940.0	....
Rubidium ..	Rb	85.45	......	....	38.0	....
Ruthenium .	Ru	101.7	......	....	>1950.0	....
Samarium ..	Sa	150.4	......	....	1350.0	....
Scandium...	Sc	44.1	......	....	1200.0(?)	....
Selenium ...	Se	79.2	2	1.477	218.5	690.0
Silicon......	Si	28.3	4	0.2638	1420.0	....
Silver.......	Ag	107.88	1	4.0248	961.0	1955.0
Sodium.....	Na	23.00	1	0.8596	97.5	742.0
Strontium...	Sr	87.63	2	1.6333	>805, 850< >Ca<Ba	
Sulphur......	S	32.07	2	0.5980	116.5	444.5
Tantalum...	Ta	181.5	......	....	2850.0	....
Tellurium...	Te	127.5	2	2.379	451.0	1390.0
Terbium....	Tb	159.2	......	....	....	....
Thallium....	Tl	204.0	......	....	302.0	1700.0
Thorium....	Th	232.4	......	....	>1700.0<Pt	....
Thulium....	Tm	168.5	......	....	....	....
Tin.........	Sn	118.7	2	2.2188	231.9	2270.0
Titanium...	Ti	48.1	4	0.4490	1795.0±15.0	....
Tungsten...	W	184.0	2	3.4308	3540.0	....
Uranium......	U	238.2	......	....	Near Mo.	....
Vanadium...	V	51.0	......	....	1720.0±20.0	....
Xenon.......	Xe	130.2	0	....	−140.0	−109.0
Ytterbium..	Yb	173.5	......	....	1800.0(?)	....
Yttrium....	Yt	88.7	......	....	1200.0(?)	....
Zinc........	Zn	65.37	2	1.2194	419.3	918.0
Zirconium...	Zr	90.6	......	....	2350.0(?)	....

NOTE.—In addition to the above elements, there is some reason to believe in the existence of a gas "coronium" (so called from its existence in the solar corona) which would form 0.00058 per cent. of the earth's atmosphere according to DR. A. WEGENER'S calculations (*Science*, Oct. 31, 1913).

[1] In those cases in which a metal has two valences, the valence given corresponds to the electrochemical equivalent, and may not necessarily be the commoner one.

A SHORT ACCOUNT OF THE COMMON METALS AND METALLOIDS

Aluminum.—Atomic weight, 27.1; trivalent; sp. gr., cast, 2.56; rolled, 2.66. A silver-white metal; breaks with crystalline fracture. Melts at 657°C.; volatilizes at a very high temperature; specific heat from 0° to 100°C., 0.2270 (mean); latent heat of fusion, 100 cal.; coefficient of linear expansion, 0.0000231; heat conductivity, 31.33 (Ag = 100). Is friable at 530°C. The tensile strength of cast aluminum is about 15,000 lb. per sq. in., but this may be increased by drawing to 35,000 lb. per sq. in. Its conductivity is about 58 (Ag = 100).

The metal cannot be reduced with carbon; but forms a carbide Al_4C_3; and a nitride AlN. It is reduced by sodium from its compounds. Said to be paramagnetic, susceptibility 0.6×10^{-6}. Is very malleable between 100° and 150°C. Is notable for the lightness of its alloys, and for its energetic reduction of oxides of other metals (thermit process). It cannot be produced by direct electrolysis in aqueous solution but is deposited electrolytically from a solution of its oxide in cryolite. The oxide forms the base of most artificial gems.

Antimony.—Atomic weight, 120.2; trivalent usually; sp. gr. 6.71; melts at 632°F., and volatilizes at about 1,500°C. Is in no degree malleable or ductile; its electric conductivity is 4.2 (Ag = 100). Has extremely crystalline structure; coefficient of linear expansion, along axis 0.0000168; normal to axis 0.0000089. It may readily be crushed to powder. Hydrochloric acid has a slight solvent action on it; nitric acid converts it to the pentoxide; sulphuric acid first oxidizes it and then converts it to sulphate. Chlorine reacts directly with the metal, forming anhydrous chloride. The classic process for the recovery of antimony is its liquation as sulphide, Sb_2S_3, from rich ores and the subsequent throwing down of the antimony by melting with scrap iron. It is also recovered by subjecting the ore to an oxidizing roast, driving off the antimony in fume, which is caught and reduced to metal. Antimony can also be recovered by lixiviation of the ores with sodium sulphide, obtaining either Na_3SbS_3 or Na_3SbS_4. From these solutions it can be regained either chemically or by electrolysis. Another important source of antimony is in refining argentiferous lead. Before mixing in zinc for the PATTINSON process the lead is oxidized slowly for some time to purify it (softening process). The slag thus formed runs high in antimony from which it is recovered as antimonial lead.

In refining crude antimony (not hard lead) the crude metal is fused with 8 to 12 per cent. of Sb_2S_3 and 4 to 5 per cent. of NaCl to bring it up to 98 to 99 per cent., and then it is given a final purifying by "starring," in which it is melted in the presence of Sb_2S_3 and soda ash. No iron must be allowed to get into it during this process; so the iron ladles, etc., are kept well covered with whitewash.

Argon.—Occurs in the air to the extent of 0.935 per cent.

It can be prepared by passing atmospheric nitrogen, free from oxygen and moisture, over red-hot magnesium ribbon; magnesium nitride is thus formed while the argon does not combine.

Arsenic.—Atomic weight 74.96; trivalent usually; sp. gr., crystalline 5.73, amorphous 4.71; a brittle steel-colored metal, volatilizes at 450°C., without melting. The metal and the pentavalent compounds are not poisonous, but the metal easily oxidizes and the pentavalent form easily reduces to the extremely poisonous trivalent form. Forms a very volatile hydride AsH_3, which serves as the basis for the famous MARSH test. Most of the arsenic on the market is recovered from flue dust, in which the arsenic concentrates. This is roasted in reverberatories and the roasted arsenious oxide condensed in large chambers.

Barium.—The properties of this metal are still in doubt, as it is probable that it has not yet been prepared in a high degree of purity. The impure form is prepared by reducing the oxide with magnesium. The peroxide, BaO_2, formed by heating BaO to 500°C. in the presence of air, serves as the basis of hydrogen peroxide manufacture. At a still higher temperature it again gives off oxygen.

Beryllium.—Atomic weight, 9.1; bivalent; sp. gr. 1.842. A soft,[1] lustrous, white, malleable metal. Melts at 1800°C.[1] Does not volatilize at 1900°C. Burns like magnesium when in powder or ribbon. Withstands water better than magnesium, but this apparent inertness may be due to a film of oxide. Prepared by electrolyzing a mixture of sodium and beryllium fluorides, or by decomposition of the fluoride by sodium, potassium or magnesium.

Bismuth.—Atomic weight, 208; trivalent; sp. gr., 9.80; the metal is neither malleable nor ductile; it melts at 266°C. and volatilizes between 1100 and 1450°. Electric conductivity, 1.3 (Ag = 100). This metal is remarkable in that it expands on solidifying; its sp. gr. is about 10.055 just above the melting point. It is the most diamagnetic material known. Is obtained: (1) by liquation in crucibles or retorts of ores carrying native bismuth; (2) by reduction processes, using Na_2CO_3 as a flux, beside CaO and FeO, since the fusion temperature of the slag must be low; (3) as a by-product of electrolytic lead refining; (4) as a by-product of steam Pattinsonizing (HULST process); (5) as a result of the wet treatment of the last oxide coming from the cupellation of lead-silver bullion. Some of its alloys melt at remarkably low temperatures (see fusible metals under "alloys").

Boron.—The element is found in nature as boric acid and borax. It is obtained by reduction as a brown amorphous powder, which, on dissolving in molten aluminum, separates on cooling in crystalline form, said to rival the diamond in hardness. The suboxide is an energetic deoxidizer, recommended by WEINTRAUB for insuring high-conductivity copper castings.

[1] FICHTER AND JABLCYZUSKI say it will scratch glass after fusion and melts at 1280°C. Berichte, XLVI, No. 7.

Bromine.—Occurs in the mother liquors of certain salt-wells in the United States and at Stassfurt, Germany. It is liberated from these liquors by the action of chlorine, or by direct electrolysis. It is, at ordinary temperatures, a fuming red liquid of unbearable odor, from which it takes its name. It is more active than iodine and less than chlorine.

Cadmium.—Atomic weight, 112.4; always bivalent; sp. gr., cast, 8.60; white metal of bluish tinge, intermediate in hardness between tin and zinc. Melts at 320°C.; boils at 778°C., so can be separated from zinc by volatilization. Is precipitated from solution by zinc. Is remarkable for its fusible alloys: thus, 2 parts Bi, 1 part Sn, 1 part Pb melt at 93.75°C.; but with 10 per cent. Cd added melt at 75°C., while Cd 14.3, Sn 19.0, Pb 33.1 and Bi 33.6 melt at 66°C. Its metallurgy is simply that of a by-product of zinc. It is greatly concentrated in the first zinc dust formed in roasting the ores. The cadmium may then be freed from the zinc in a wet way owing to the fact that if a mixture of cadmium and zinc oxides be treated with insufficient sulphuric acid to dissolve both, the cadmium will be dissolved before the zinc will. Moreover, if a mixture of cadmium and zinc sulphates be agitated with a mixture of cadmium and zinc oxides, the cadmium will be dissolved and zinc oxide will be precipitated. It is eventually freed from the last zinc by electrolysis, if a very pure metal be desired. If this is not necessary, advantage is simply taken of the fact mentioned above, that CdO is more volatile than ZnO, and also that CdO reduces at a lower temperature than does ZnO, and that CdO precipitates Zn from $ZnSO_4$ as ZnO.

Cæsium.—Of no commercial value. Atomic weight, 132.8. Discovered by KIRCHOFF in the Dürkheim mineral water. Its spectrum contains two characteristic blue lines, whence its name.

Calcium.—Atomic weight, 40.07; bivalent; sp. gr., 1.85. A lustrous, silvery-white brittle metal. It is less malleable than the alkali metals; shows a crystalline fracture. It melts *in vacuo* at 760°C. It forms a hydride, CaH_2; a nitride, Ca_3N_2 and a carbide, CaC_2. It is a powerful deoxidizer. Cannot be reduced by carbon. The metal can be cut with a knife and will scratch lead but not calc spar.

Cerium.—Atomic weight, 140.25; sp. gr., 6.73. It has an iron-gray color, is soft, being somewhat harder than lead, is malleable and easily rolled. Fuses at about 800°C. Its most remarkable property is that of combining with heavy metals, such as iron or copper, to form dense but easily oxidizable alloys (the pyrophoric alloys). Fine wire made from the metal burns with a brilliancy even exceeding that of magnesium. It dissolves easily in dilute acids, but only to a limited extent in cold concentrated sulphuric or nitric acid. It will reduce the oxides of most metals or metalloids. On filing or scraping cerium with a knife, the filings or scrapings will take fire. It can be prepared by fusion of the anhydrous chloride, but not by direct reduction of its oxide by carbon, as a carbide is

formed. Lanthanum, præseodymium and neodymium greatly resemble it. Cerium fluoride is used in the "flaming-arc" lamp.

Chlorine.—Atomic weight, 35.46. Gas at ordinary temperatures. It derives its name from its greenish-yellow color. Strongly corrosive to organic tissues as well as to most metals. A violent poison. Liquefies readily. It is much used in commerce as a bleaching material, for which it is derived by the WELDON process (*q.v.*), or by electrolysis of sodium chloride solutions (CASTNER-KELLNER, GIBBS process, etc.). The hypochlorites form the basis for many disinfectants; the chlorates form the basis of many modern explosives.

Chromium.—A bright gray, very lustrous, very hard crystalline metal. Atomic weight, 52.0; sp. gr., 6–7. It oxidizes slowly in cold air, readily on heating. Does not burn so readily as iron on heating in oxygen. Combines readily with the halogens, sulphur, silicon and carbon.

Chrome-iron ore can be directly smelted with carbon to give ferrochrome. To obtain pure chromium the chrome-iron ore is roasted with sodium carbonate or sodium carbonate and lime. The mass should not be fused. From this sintered mass sodium chromate can be leached out. If H_2SO_4 is added to sodium-chromate solutions the bichromate is produced. Sodium bichromate can be reduced with sulphur to give chromous anhydride, which can then be reduced with carbon or with aluminum. In the carbon reduction the metal is not fused, but remains as a powder. Chromium alloys readily with iron, manganese, cobalt and tungsten; with other metals only with difficulty. It can also be prepared by aluminum reduction.

Cobalt.—Atomic weight, 58.97; trivalent; sp. gr. 8.66–8.92. A silver-white metal, melts at 1497°C. (KALMUS). Yield point, 31,200–65,600 lb. per sq. in. Specific heat, 0.1056 (15°–100°). This is the most magnetic element except iron. Exceeds iron both in hardness and tenacity. May be turned with ordinary lathe tools. Brinnell hardness, chilled from melting point, 90.8; annealed from 250°C., 77.3. Cobalt may be separated from nickel when both are in solution by precipitation with milk of lime or with calcium hypochlorite; the cobalt comes down first.

Copper.—Atomic weight, 63.57. The only red metal. Bivalent. Tough; ductile. The best conductor of electricity (except perhaps silver); the third best conductor of heat. Recovery of copper is chiefly by smelting sulphide ores to give a copper-iron sulphide, the earthy materials forming a fusible slag, then blowing air through the sulphide (known as matte) getting metallic copper, sulphur dioxide, and ferrous oxide, which is slagged by addition of silica. This smelting may be done in either blast or reverberatory furnaces. The metal from the desulphurizing operation (converting) is then furnace refined if non-argentiferous, or by electrolysis if silver-bearing. Copper is also produced by direct reduction of oxide and carbonate or roasted sulphides to metal (black copper) and by wet processes, as at Rio Tinto, Wallaroo, Chuquicamata, etc.

A preliminary concentration of the copper minerals in an ore by gravity or flotation is also much practised.

Fluorine.—A slightly greenish-yellow gas, occurring in nature chiefly in fluorspar. One of the most active of the elements. Combines with hydrogen even in the dark. It is the only element except those of the argon group which will not combine with oxygen. It attacks all metals except platinum and gold, and decomposes most organic compounds. It is used to etch on glass (as HF), as an electrolyte in lead refining (as H_2SiF_6), as a valuable flux (as CaF_2), and in the manufacture of aluminum (as Na_3AlF_6).

Gallium.—A rare metal which, although tough, may be cut with a knife. With aluminum it forms a liquid alloy which will decompose water.

Gold.—Atomic weight, 197.2 (O = 16); trivalent; sp. gr., 19.29–19.37; the only yellow metal; most malleable and ductile of all metals; softer than silver, harder than tin; tenacity, about 14,000 lb. per sq. in. with 30.8 elongation. Melts at 1063°C., begins to volatilize at 1100°C. and volatilizes four times as fast at 1250°C. Electric conductivity 76.7 (Ag = 100). One oz. of gold leaf covers about 160 sq. ft. U. S. gold coin is 900 parts gold, 10 parts copper. Gold is recovered either by purely mechanical concentration (panning, etc.), by amalgamation, by dissolving it in chemical reagents (chlorination, cyanidation) or by recovering it in a fusion process with copper or lead. Has very small tendency to absorb gases when molten, but absorbs about 0.7 per cent. H, CO, and other electropositive gases when cold, if it is finely divided. It is dissolved by no one acid except nitrous, but is dissolved by any mixture (such as *aqua regia*) generating chlorine and bromine. Except in the thiosulphate, it does not play the part of base to oxy-acids.

Gold possesses the lowest solution tension of any metal. It may be precipitated from its solution by even the weakest reducing agents, such as H, P, As, Sb, C, by nearly all metals (except from cyanide solution, from which it can be separated only by zinc and metals more electropositive than zinc), by metallic sulphides, by protosalts of iron, tin, etc., by hypophosphites, sulphites, SO_2, the lower oxides of nitrogen, arsenic, oxalic acid, etc.

Helium.—First discovered by spectroscopic observation of the sun. One of the rarest of the elements on the earth's surface. Found in some uranium minerals, is given off by the gases of certain springs, and is found in the air in the proportion of 0.0005 per cent. It is absolutely inactive.

Iodine.—Atomic weight, 126.92. Occurs at ordinary temperatures as beautiful violet to black crystals. It is largely used in the aniline color industry, in making iodoform and in potassium iodides in photography and medicine. The chief sources of iodine are the mother liquors of the Chilean nitrate industry and the ashes of sea weeds. It is readily precipitated from iodates thus:

$$2NaIO_3 + 3Na_2SO_3 + 2NaHSO_3 = 5Na_2SO_4 + H_2O + I_2$$

Iridium is insoluble in every acid, differs from platinum in not being soluble in *aqua regia*, although when the iridium is very finely divided it is attacked by this reagent. Fusion with acid potassium sulphate oxidizes it but does not dissolve it (distinction from ruthenium). It also oxidizes to the trioxide, Ir_2O_3 when heated with fused sodium nitrate and hydroxide, or with hydroxide alone in the presence of air, but the residue is but slightly soluble in water. Iridium may be distinguished from platinum by suspending the precipitate produced with caustic alkalis in a solution of potassium nitrite and the solution saturated with SO_2 and boiled, renewing the water so long as SO_2 is given off, all of the iridium is converted to an insoluble brownish-green basic iridic sulphite. Iridic salts are reduced by alcohol in alkaline solutions to iridous compounds soluble in hydrochloric acid. For a method of decomposing osmiridium, see "osmium," p. 250.

Iron.—A white metal of atomic weight, 55.84. Forms two series of compounds, ferric (trivalent) and ferrous (bivalent) which pass from one form to the other by very gentle reduction or oxidation.

Iron is the most magnetic of the metals. It alloys readily with most of the earth metals, only slightly with Pb and Cu. In the presence of Si, iron will dissolve more Cu than otherwise, that is cuprosilicon is dissolved more readily than is pure Cu. Fe alloys readily with C, Si, P, S and O.

Iron Metallurgy.—Iron is produced by a reducing smelting after concentration or roasting or both. The slag, usually known as cinder, differs from that of the lead and copper metallurgists in being a calcium-aluminum silicate. The use of preheated blast, often previously dried, is also at variance with non-ferrous practice. The iron produced always contains Si, C, P, S, etc. Indeed most of the usefulness of iron depends on its carbon content; so a list is herewith appended of the carbides of iron and their modifications, with the names applied to them by the iron metallurgists.

Ferrite.—Chemically pure iron: α-iron, magnetic and free from C, passes at 780°C. into β-iron, which is non-magnetic and practically incapable of dissolving C. Above 880°C. β-iron passes into γ-iron which is non-magnetic and capable of dissolving C or Fe_3C.

Cementite.—Iron carbide, Fe_3C.

Austenite and Martensite.—Solid solutions of Fe_3C in γ-iron.

Troosite.—Colloidal solution of Fe_3C in Fe.

Sorbite.—Mixtures of Fe, Fe_3C and solid solutions of Fe_3C in Fe.

Pearlite.—The eutectic between ferrite (Fe) and cementite (Fe_3C). It corresponds to 0.9 per cent. C, or (Fe_3C + 20Fe).

Temper Carbon.—Non-graphitic carbon which separates from white iron by keeping it for a long time at a temperature near 1000°C., during which time the finely divided cementite changes into a mixture of ferrite, pearlite and temper carbon.

Temper carbon is more readily oxidizable than graphite or carbide carbon.

Forgeable Iron.—The saturation point of Fe_3C in Fe is reached at 2 per cent. C (2 Fe_3C + 15Fe). Anything up to this point may be regarded as forgeable iron.

Steel Hardening.—This is explained by assuming a transformation of pearlite to martensite, and the maintenance of this solid solution by quenching.

Malleablizing.—By exposing white iron for a long time to about 1000°C., the dissolved Fe_3C is converted into Fe and C, but the carbon is not present as graphite, but in an easily oxidized state. The oxidation is then carried on by Fe_2O_3 or $FeCO_3$.

White iron is a supercooled solution and may be regarded as a metastable system between Fe_3C and Fe, in which the reaction $Fe_3C = 3Fe + C$ has not been allowed to take place.

Gray iron is a stable system Fe—Fe_3C—C. It has had time, at the different temperatures and concentrations to reach a more or less complete state of equilibrium. During the cooling some of the Fe_3C has decomposed into Fe and C, the latter being found as graphite. See also BESSEMER (p. 475), THOMAS GILCHRIST (p. 478) and SIEMENS-MARTIN (p. 478).

Krypton.—Present in the proportion of 1 : 1,000,000 in air. Inert. Has a characteristic spectrum, noticed especially in the Aurora Borealis.

Lanthanum.—Greatly resembles cerium, which see. It occurs chiefly in monazite sand.

Lead.—Atomic weight, 207.1; tetravalent; sp. gr., 11.35–11.37, when molten, 10.37–10.65; a dull gray metal, malleable but not ductile; tenacity the lowest of any common metal. Melts at about 326°C.; electric conductivity 10.7 with silver 100. Heaviest of all base metals. Fuses at 325°C.; boils at 1525°C. Has a great affinity for all the noble metals and is often used as a carrier in their extractions.

Lead is obtained by its ores by roast-reaction process ($2PbO + PbS = 3Pb + SO_2$ or $PbSO_4 + 2PbS = 3Pb + 3SO_2$); by the so-called precipitation process ($PbS + Fe = Pb + FeS$); or by reduction with carbon of oxide and carbonate ores or previously roasted sulphides. The argentiferous lead is refined by either the PARKES, PATTINSON or BETTS processes (*q.v.*, pp. 475, 476, 477).

Lithium.—Atomic weight, 6.94; monovalent; sp. gr., 0.5936. A soft silver-white metal. Melts at 186°C.; vaporizes at about 1000°C. Below 200°C. may be melted in the air; above that, bursts into flame. Decomposes water at ordinary temperatures. It is the lightest known metal.

Magnesium.—Atomic weight, 24.32; bivalent; sp. gr., 1.75. A white lustrous metal of fibrous crystalline structure. Malleable and ductile, not tough. Melts at 651°C.; boils at about 1120°C. Large pieces oxidize superficially. In powder it burns readily. Combines readily with nitrogen at elevated temperatures. Is a good deoxidizer. Lightest of metals in

common use. When powdered, it is highly combustible, burning with a vivid light.

Manganese.—Atomic weight, 54.93; usually bivalent, may be heptavalent; sp. gr. given by various authorities at from 7.39 to 8.30. Silvery, lustrous, hard, brittle, smooth fracture. Melting point, 1260°C. Volatilizes considerably even at the melting point. Boils about 1900°C. Cannot be reduced by carbon to pure metal, as some Mn_3C is always formed, but can be produced in comparative purity by reduction of Mn_2O_3 by aluminum. Is used commercially mainly as ferromanganese, which is formed by direct reduction of manganese and iron ores.

Mercury.—Atomic weight, 200.6; bivalent; sp. gr., when fluid at 0°C.,13.59, solid at − 40°C., 14.19. Silver white with bluish tinge. Melts at − 39.38°C. Contracts on solidification, forming a white, very ductile, very malleable mass, which can be cut with a knife. Specific heat from − 78° to − 40°C. is 0.0247; of the fluid metal, 0 to 100°C., 0.0333. Electric conductivity at 22.8°C. is 1.63. Heat conductivity, 67.7 (Ag = 100). Boils at 360°C (DULONG and PETIT). Amalgamates readily with gold, silver, zinc, tin, cadmium, lead and bismuth; with copper when finely divided; with arsenic, antimony and platinum with difficulty; with iron, nickel and cobalt not at all directly. Is obtained by smelting the ores and catching the flue dust, in which the mercury condenses.

Molybdenum.—Atomic weight, 95.3; quadrivalent; sp. gr., 8.62–9.01. A white, extremely lustrous, very hard metal. Acids scarcely affect it, except nitric, which converts it to molybdic oxide or acid. The sulphides readily form thio-salts with alkaline sulphides. Remains unchanged in air at ordinary temperatures, but oxidizes slowly when heated to redness. Used in high-speed steels, where it exercises about twice the influence that tungsten does. It cannot be produced pure by direct reduction of the oxide by carbon.

The reduction test for molybdenum is as follows: A small quantity of molybdate or wulfenite, in a powdered state, together with a scrap of paper, should be placed in a test-tube with a few drops of water and an equal quantity of concentrated sulphuric acid. The tube and its contents should then be heated until the acid fumes begin to come over. After allowing the tube to cool, water should be added, a drop at a time. The addition of the first drops gives rise to a deep blue color, which disappears as more water is added.

Neodymium.—Greatly resembles cerium, which see.

Nickel.—Atomic weight, 58.58; sp. gr., cast, 8.35, rolled or hammered, 8.6 to 8.9; is very hard; can be rolled to sheets not over 0.0008 in. thick and drawn into a wire 0.0004 in diameter. According to SHAKELL the tenacity is 42.4 tons per sq. in. for annealed wrought nickel. It melts at 1452°C. when pure; the melting point is considerably lowered by carbon. Nickel is attracted by a magnet (Ni : Fe :: 1 : 1.54), but it loses this power at 340°C. Its electric conductivity is 12.9 (Ag = 100). The metallurgy of nickel somewhat resembles the fire metallurgy

of copper, in that the ores are smelted, following either wet concentration or roasting, or both, and the nickel-copper matte is bessemerized, but the converting process is not carried so far as in copper. In constitution nickel matte seems to vary, as the nickel content increases, from (Ni_2S and FeS) to (Ni_3S_2 and FeS) to pure Ni_3S_2 or even a solution of Ni in Ni_3S_2. Nickel speiss consists of Ni_5As_2, NiAs and probably Ni_3As_2. The partly bessemerized mattes and speisses are then given the so-called "top and bottom smelting"—a reducing fusion with sodium sulphate. The product of this fusion consists of a layer of slag, a Cu-Fe-Na matte, and a Ni-Fe matte at the bottom. By repeated top and bottom smeltings a copper matte practically free from nickel and a nickel matte practically free from copper are obtained.

The nickel matte is then worked up by one of numerous wet processes. A part of the present Ni-Cu matte from the Canadian Copper Co.'s works is worked down into metal (the so-called monel metal) without separation of the nickel, copper and iron. The electrolytic baths are probably neutral sulphate containing considerable amounts of borate. An interesting method of nickel recovery from products in which the nickel occurs as oxide, oxide ores or wasted sulphides is the Mond process. A reducing roast is given the ores in retorts heated to 300°C. with gases containing H, whereby the nickel oxide is reduced to sponge Ni. The reduced nickel is then exposed to gas containing CO at 100°C. and 15 atmospheres pressure. Volatile nickel carbonyl is formed. This is stable at 50°C. at 2 atmospheres pressure; at 100° at 15 atmospheres; at 180° at 30 atmospheres; and at 250° at 100 atmospheres. The vapors of $Ni(CO)_4$ escaping from the vessels under pressure can be dissociated by simply lowering the pressure. The electrolyte formerly used by the Balbach works was said by Ulke to be a hot nickel sulphite, the current density to be 15 amp. per sq. ft. and a tank voltage of 1.7–1.8 volts.

Osmium.—The heaviest of all metals; sp. gr., 22.48; atomic weight, 190.9. Osmium is volatilized in, but not melted by the oxyhydrogen blowpipe. When strongly heated in contact with air the finely divided metal burns to osmic anhydride, OsO_4 (usually known as osmic acid). This oxide is remarkable for its peculiar, exceedingly irritating and offensive odor. It is injurious to the eyes and is extremely poisonous. This oxide is soluble in water, giving a neutral solution, from which it is precipitated by nearly all metals, even silver, as a black precipitate. Fuming nitric acid or *aqua regia* also oxidizes osmium to OsO_4. When intensely ignited, osmium is rendered insoluble in acid, and must be fused with niter and distilled with HNO_3, when OsO_4 will distil over. All compounds of osmium yield the metal when ignited in hydrogen. Osmiridium may be attacked by mixing it with common salt or potassium chloride and exposing it in a glass or porcelain tube to a current of moist chlorine gas. Osmic acid is formed, which volatilizes below 212°C. and can be condensed and fixed by passing the

fume into an alkaline solution. Iridium remains behind in the tube as a double chloride, $2KCl \cdot IrCl_4$.

Palladium is the most fusible of the so-called platinum metals. The metal oxidizes when heated in air. It absorbs hydrogen to a large extent. A solution of iodine produces a black stain on palladium, but has no effect on platinum. The best solvent for palladium is *aqua regia*. It is sparingly soluble in pure nitric acid, but dissolves more readily in fuming nitric acid, forming palladious nitrate, $Pd(NO_3)_2$. All palladium compounds decompose on ignition.

Phosphorus.—Found in nature chiefly as the tri-basic calcium phosphate. To produce phosphorus the calcium phosphate is treated with sulphuric acid in lead-lined tanks. This converts the tricalcium into monocalcium phosphate. The clear solution is then drawn off and the precipitate thoroughly washed. The solution and washings are evaporated to 45°Bé. and about 25 per cent. of coke or charcoal added and the pasty mass dried in iron pans. The dry mixture is then distilled in cast-iron retorts and the fumes passed into a condenser containing water, under which the phosphorus collects. Phosphorus melts at 44°C. and distills at 269°C. It must be kept under water.

Platinum.—Atomic weight, 195.2; tetravalent; sp. gr., cast, 21.5; a white metal of a grayish tinge; is very malleable and ductile; harder than copper, silver and gold; tenacity about 23,000 lb. per sq. in. (Deville and Debray); electric conductivity 13.4 at 0°C. (Ag = 100); melts at 1710°C., but is sensibly volatile at 1300°C. Is mainly recovered from alluvial deposits, but is also got in Wohlwill's process of electrolytic gold refining, where it remains in the solution. It is affected by fused alkaline hydroxides, phosphorus, cyanides, sulphides and halogens. Platinum is not acted upon either by pure hydrochloric, nitric or sulphuric acid. It dissolves in *aqua regia* and other mixtures, evolving chlorine, but less readily than gold, so that gold which has been fused to platinum can be dissolved by dilute *aqua regia* at moderate temperatures without injuring the platinum. When alloyed with silver, lead and some other metals it is dissolved (see tables on pp 312, 313).

Potassium.—Atomic weight, 39.1; monovalent; sp. gr., 0.865. A bluish-white metal, softer than sodium; fuses at 62.3°C., vaporizes about 700°C. The vapor is greenish. Like sodium in its reactions (*q.v.*). However, there is an explosive material left in the retorts when potassium carbonate is reduced by carbon, and the process is dangerous. It is found in greatest abundance in the salt deposits of Stassfurt, Germany.

Præseodymium.—Greatly resembles neodymium, which see. Occurs chiefly in monazite sands.

Rhodium is found in the insoluble residue resulting from the treatment of crude platinum with *aqua regia*. It is, when pure and in a compact state, not acted upon by even *aqua regia*, but when alloyed with lead, copper or bismuth in certain pro-

portions it dissolves in it. When alloyed with gold or silver it does not dissolve. It is oxidized by air at a red heat, or by fusion with potassium hydroxide and niter. It is converted by fusion with acid potassium sulphate into the soluble potassium rhodic sulphate $K_6Rh_2(SO_4)_6$. Mixed with sodium chloride and ignited in chlorine it forms the easily soluble $3NaCl\text{-}RhCl_3 \cdot H_2O$. Rhodium is distinguished from the other platinum metals by its insolubility in *aqua regia*, its solubility in fused $HKSO_4$, and the formation of a brown precipitate on adding KOH and alcohol to rhodium-chloride solution.

Ruthenium is found in the insoluble residue resulting from the treatment of platinum ore with *aqua regia*. It is a grayish-white metal, closely resembling iridium and very difficultly soluble. When heated in air it becomes covered with bluish-black ruthenic oxide, Ru_2O_3. When pure it is unacted on by acid, and is scarcely acted on by acid potassium sulphate. It is attacked by fusion with potassium hydrate and niter, or potassium chlorate and is converted into K_2RuO_4, a dark-green mass, soluble in water to an orange-colored fluid which stains the skin black. Ruthenium is rendered soluble by ignition with potassium chloride in a current of chlorine, being converted to $2KCl \cdot RuCl_4$.

Selenium.—An element originally recovered from the dust chambers and mud of the lead chambers of sulphuric-acid plants. The classic process is to leach the mud with concentrated potassium cyanide, forming KCNSe, and then precipitating the Se by adding hydrochloric acid. My own process, by which much of the commercial selenium is now obtained, is to oxidize seleniferous flue dusts with HCl and $NaClO_3$, then after all the free chlorine is gone, precipitate the metal with sulphur dioxide. The precipitate is then washed and dried. Selenium occurs in several amorphous modifications, some soluble in CS_2, some insoluble; in certain crystalline forms when precipitated from solution; in a vitreous form when melted and cooled quickly; and a so-called metallic form when melted and cooled slowly. This metallic modification has the remarkable property of altering its electric conductivity when illuminated. The vitreous modification passes over into the metallic when heated for some time above 180°F. There is a considerable evolution of heat during the change.

Silver.—Atomic weight, 107.88; monovalent; sp. gr., cast 10.50, minted 10.57. Melts at 962°C., boils at 1850°C. MOISSAN). It is the whitest of metals, harder than gold, softer than copper, more malleable and ductile than any metal except gold, the best conductor of heat and electricity of known substances. (Some authorities state that gold is the best conductor of heat and copper of electricity. In any case the difference is slight.) It volatilizes at high temperatures, yielding a green vapor. In the molten state it has the property of absorbing twenty-two times its volume of oxygen, which is given out on cooling, causing the so-called spitting of silver. This occurs only with the pure metal. Small quantities of copper, bismuth

and zinc entirely prevent it, as does also an inert cover. Arsenic antimony, bismuth and lead render silver brittle. It is recovered by amalgamation, by chemical processes (AUGUSTIN, ZIERVOGEL, KISS, RUSSELL, PATERA, Patio, Cyanide, etc.) and from the impure bullion from lead or copper smelting. From lead it is recovered by the PATTINSON, PARKS and BETTS processes (*q.v.*) and from copper by electrolytic parting. In both these cases it contains gold, which is then recovered either by dissolving the silver by sulphuric or nitric acid, or by electrolytically refining the silver by the MOEBIUS or THUM process. The auriferous silver bullion is known as doré. Silver does not oxidize in air, even if heated, but is easily attacked by sulphur and its compounds. It is attacked by nitric acid, and by hot sulphuric, scarcely at all by hydrochloric nor by the halogens and not at all by fused alkaline hydroxides.

Sodium.—Atomic weight, 23.00; monovalent, sp. gr., 0.974. A soft silvery-white metal, which may be kneaded at ordinary temperatures. Melts at 95.6°C.; vaporizes at about 900°C. Dissolves in anhydrous ammonia. Decomposes water at ordinary temperatures, and must be kept under oil. Burns in dry air to the peroxide, Na_2O_2. Practically all sodium compounds are soluble. Can be reduced from the carbonate by carbon.

Strontium.—A soft white metal. Found chiefly in nature as carbonate and sulphate. Is used in the manufacture of fireworks for red fire, and in the refining of sugar.

Tantalum.—Atomic weight, 181.5. A rare element usually occurring with columbium. Below 200°C. the metal is not attacked by air, oxygen or any acid except concentrated hydrofluoric. Not attacked by *aqua regia*, or by alkaline solutions, but is by fused alkalies. Can be used for electrolytic cathodes, but not as anodes, as it oxidizes under anodic action.

Tellurium.—A metal much like selenium. Occurs usually as gold or silver telluride. About the only method of separating from selenium, if the two are mixed, is to make a fractional separation with SO_2, for selenium precipitates from concentrated hydrochloric-acid solutions with SO_2, while tellurium does not, or by taking a mixture of finely divided precipitates, leaching with concentrated cyanide solutions at ordinary temperatures, heating the solution, and filtering hot. The selenium is dissolved.

Tin.—Atomic weight, 119.0; quadrivalent; sp. gr., cast 7.287, rolled 7.30, tetragonal form (electrolytically deposited) 7.25, rhombic 6.55, ordinary commercial about 7.5, friable modification (due to tin pest) 5.8; melts at 232°C.; boils at 2100°C.; specific heat, 0.0562; coefficient of linear expansion, 0.00223; heat conductivity, 15.2 (Ag = 100). Most malleable at about 100°C., most brittle at about 200°C. Rolls to sheets not over $\frac{1}{6000}$ inch thick. Tensile strength of very pure bars 2420 lb. per sq. in. (H. LOUIS), of hammered 2540 lb. per sq. in., commercial about 4600 lb. per sq. in., tin foil about 5980 lb. per sq. in. Breaks down at low temperatures to a gray granular

powder (tin pest); the change commences at 18°C., and is most rapid at −48°C. Boils at 1500° to 1600°C. if heated out of access of air. It is but little affected by air and moisture at ordinary temperatures. Electric conductivity, 14.4 (Ag = 100). Decreases in volume by 6.75 per cent. on solidification. Acted on by Cl, HCl, H_2SO_4 and HNO_3, but is only oxidized by latter and does not form nitrates. Ores are usually concentrated, roasted if required and smelted in shaft or reverberatory furnaces, and refined by fire processes. Analyses of English tin show (H. Louis, "Metallurgy of Tin"): Sn, 98.64–99.76; Fe, tr–0.13; Pb, 0–0.20; Cu, tr–1.16. Tin from Pulo Brani showed, Sn, 99.76; Sb, 0.07; Pb, 0.02; Fe, 0.14; Cu, As, none. Is perceptibly volatile at 1200°C. Because of the high specific gravity of tin oxide it is ordinarily concentrated by mechanical means before smelting. The smelting of tin is difficult because it tends, when there is an excess of base in the slag, to enter it as an acid, forming stannites and stannates, while if there is an excess of silica tin enters the slag as a base.

Tungsten.—An almost white, very lustrous hard metal. Atomic weight, 184.0; sp. gr., 18.7–19.1. It begins to oxidize only at elevated temperatures in air. It can be reduced by carbon from the oxide. Ductile tungsten is practically insoluble in the common acids, it has the highest melting point of any metal (3000°C.); it is paramagnetic, and its wire can be drawn to smaller sizes than can the wire of any other metal. The chief commercially important forms are sodium tungstate, largely used for fireproofing and as a mordant, and tungsten as a constituent of high-speed steels. The recovery is entirely by chemical methods: (1) fusion with sodium carbonate; leaching out sodium tungstate with water; precipitation of WO_3 by acidifying with hydrochloric acid, followed by reduction with carbon. A little W_2C and WC is formed in this reduction and dissolved by the metal. Ferrotungsten can also be formed by direct reduction of wolframite or scheelite with iron compounds and powdered quartz or glass. The carbon-free metal can also be produced by the aluminum-reduction process.

A general test for all tungsten ores is carried out as follows: Strong hydrochloric acid is added to the ore, which is first pulverized to as fine a powder as possible, and part of the tungsten will pass into the solution. Metallic zinc should then be added and the mixture boiled. A fine azure blue denotes the presence of tungsten.

When any ore containing tungsten is fused with sodic carbonate, leached out with hot water and filtered, the tungsten passes into the filtrate. If hydrochloric acid is added the tungsten is precipitated. This precipitate is insoluble in all acids, dissolves readily in ammonia, and is of a fine yellow color. A little of this yellow powder, if added to a bead of salt of phosphorus and treated in a reducing flame, using a blow lamp, gives the fine blue bead characteristic of tungsten.

Uranium.—A white lustrous, very hard metal, oxidizing in

air only at high temperatures, but igniting in pure oxygen at 170°. Fluorine attacks it at ordinary temperatures, chlorine at 180°, bromine at 210° and iodine at 260°C. It combines with sulphur at about 1000°C. to form a black sulphide and with nitrogen at about 1000°C. to produce a yellow nitride.

Vanadium.—Atomic weight, 51.0; sp. gr., 5.50; melts at 1720°. According to BORCHERS the purest metal yet obtained was a gray lustrous powder which ignites readily in the Bunsen flame. It dissolves with great difficulty in hydrochloric or dilute sulphuric acid, but more readily in strong sulphuric acid, in hydrofluoric acid or in nitric. With fused alkali-metal hydroxides it forms vanadates. At elevated temperatures it combines readily with the halogens, sulphur, or even with nitrogen.

Xenon.—Occurs in the atmosphere in the proportion of 1:20,000.

Zinc.—Atomic weight, 65.37; always bivalent; sp. gr., cast, from 6.861 to 7.149; when rolled, 7.2 to 7.3; when fluid, 6.48 to 6.55. Boils at about 920°C. Melts at 415°C. Specific heat at 0° to 100°C., 0.09555 (REGNAULT); probably 0.1015 from 100° to 300°C. It burns in air at about 505°C. Zinc is brittle at ordinary temperatures, especially if impure, but between 100°C. and 150°C. it becomes malleable and ductile, and may be rolled into sheets and drawn into wire, and retains these properties after cooling. At 205°C. it again becomes so brittle that it may be powdered in a mortar. When cast at a temperature near its melting point it is more malleable than when cast at a higher temperature. In malleability zinc ranks between lead and iron; in ductility between copper and tin. In hardness it stands between copper and tin; more exactly between silver and platinum, being 2.5 on MOH's scale, 6 on TURNER's sclerometer, and 1077 on BOTTONE's scale, on which the diamond is 3010. The thermal conductivity is given from 19 (WIEDEMANN) to 64.1 (CALVERT and JOHNSON), silver being 100. Its electrical conductivity is 16.92, mercury at 0°C. being unity. On the basis of silver = 100, BECQUEREL gives its conductivity at 24.06, and WEILLER at 29.90. According to ROBERTS-AUSTEN the coefficient of linear expansion is 0.0000291; CALVERT and JOHNSON give it at 0.00002193 for hammered zinc. The tensile strength of zinc varies from 2700 lb. per sq. in. for cast metal to 17,700 for an annealed rod. Zinc dissolves readily in both acid and alkaline solutions with evolution of hydrogen. A moderate tenor in lead makes zinc malleable and ductile; over 1.5 per cent. Pb is certainly detrimental. Iron up to 0.2 per cent. does not greatly affect the properties of zinc, above that it makes it less fluid, less malleable, less strong, harder and more brittle. Cadmium seems to have no injurious influence except when the spelter or ore is to be used for making zinc oxide. Copper makes zinc harder and more brittle, even if only 0.5 per cent. be present. Tin also makes it harder and more brittle. Other impurities are of minor importance, but silver, thallium, indium, magnesium, aluminum, antimony, arsenic, sulphur, carbon, chlorine and oxygen occur. The metal

is produced by smelting the ores in retorts with carbon as a reducing agent, and extraneous fuel to heat them. A fusible slag is not wanted. Sulphide ores must be roasted clean before distillation. The loss of zinc in the smelting process, due to retort absorption, escape through the pores of the retorts, escape of uncondensed zinc through the adapters, through zinc left in the retorts, etc., is very seldom below 10 per cent. and may amount to 25 per cent.

Zirconium.—Atomic weight, 90.6; sp. gr., 6.4; melts about 2350°C., occurs as the natural oxide and as the silicate (zircon). It was used as the incandescing material in the first gas mantles.

DETECTION OF THE METALS

Aluminum.—Is precipitated as white gelatinous hydroxide by ammonia. When the oxide is strongly heated on charcoal with cobalt nitrate, a bright-blue mass is obtained. With soda before the blowpipe it swells and forms an infusible compound.

Antimony.—When a small quantity of an antimony compound is heated in the upper reduction zone of a Bunsen burner on a thread of asbestos, the flame is given a bluish tinge and when a small porcelain basin filled with cold water is held above it, a brownish-black deposit of metallic antimony is deposited upon the basin, and this is but slightly attacked by cold nitric acid and is insoluble in sodium hypochlorite. Arsenic gives a similar reaction, but arsenic gives a garlic-like odor during the reduction, and the metallic film is readily soluble in the hypochlorite. Antimony compounds may be obtained in solution by treating with HCl or by fusing first with potassium carbonate and potassium nitrate. Hydrogen sulphide produces in acid solution a very characteristic orange-red-colored precipitate of antimony trisulphide. Blowpipe tests—on coal, reducing flame, volatile white coat, bluish in thin layers, continues to form after cessation of blast. With bismuth flux on plaster, orange-red coat, made orange by $(NH_4)_2S$; on coal, faint yellow or red coat. In open tube, dense, white, non-volatile amorphous sublimate. The sulphide, too rapidly heated, will yield spots of red. In closed tube the oxide will yield a white fusible sublimate of needle crystals; the sulphide, a black sublimate, red when cold.

Arsenic.—Mix with sodium carbonate and heat on charcoal with the blowpipe. All arsenic compounds give a garlic odor. Add to concentrated hydrochloric acid a few drops of an arsenite solution and half a cubic centimeter of saturated solution of stannous chloride in hydrochloric acid, warm, and the solution turns brown, then black. Blowpipe—on smoked plaster gives a white coat of octahedral crystals. The action on coal has already been spoken of. With bismuth flux on plaster Sb gives a reddish-orange coat, made yellow by $(NH_4)_2S$; on coal a faint yellow coat. In open tube it gives a white sublimate of octahedral crystals. Too high heat may form

brown suboxide or red or yellow sulphide. In closed tube may give white oxide, yellow or red sulphide, or black mirror of metal. Flame—azure blue.

Barium.—The Bunsen flame is colored a yellowish-green tint when any volatile barium compound is brought into it. Soluble barium salts are distinguished from those of strontium and calcium inasmuch as they are immediately precipitated by a solution of calcium sulphate. Blowpipe—on coal, with soda, fuses and sinks into the coal. The yellow-green flame can be improved by moistening with HCl.

Bismuth.—On charcoal with soda, bismuth gives a very characteristic orange-yellow sublimate. Brittle globules of the metal are also reduced on the charcoal when treated with soda. Hydrogen sulphide precipitates from solutions of bismuth salts a blackish-brown sulphide (Bi_2S_3) insoluble in ammonium sulphide and easily soluble in nitric acid. Ammonia throws down a white basic salt insoluble in excess. Blowpipe—with bismuth flux (sulphur, 2 parts; potass. iodide, 1 part; potass. bisulphate, 1 part) on plaster, bright scarlet coat surrounded by chocolate brown with sometimes a reddish border. The brown may be made red with ammonia. With bismuth flux, on coal, gives a bright-red coat with sometimes an inner fringe of yellow.

Cadmium.—Cadmium is precipitated as a yellow sulphide by hydrogen sulphide. The sulphide is insoluble in ammonium sulphide and in the caustic alkalies. On charcoal with soda, compounds of cadmium give a characteristic sublimate of the reddish-brown oxide.

To test for cadmium in a sulphide, roast it to oxide, and reduce some of the oxide in the upper reducing flame of the Bunsen burner, at the same time holding a glazed porcelain dish which contains water just above the flame to receive a brown coating. To the brown coating add a drop of $AgNO_3$ solution; if Cd is present, black metallic silver will be deposited. Blowpipe—on coal, reducing flame, greenish yellow in thin layers. Beyond the coat, at first part of operation, the coat shows a variegated tarnish. On smoked plaster with bismuth flux Cd gives a white coat made orange by $(NH_4)_2S$. With borax or sodium phosphate, oxidizing flame, clear yellow hot, colorless cold, can be flamed milk white. The yellow bead touched to $Na_2S_2O_3$ becomes yellow.

Cæsium.—H_2PtCl_6 produces a bright-yellow crystalline precipitate, a brighter color than the potassium salt thus produced, and is much more soluble than the potassium salt. The flame test is reddish violet, similar to potassium.

Calcium.—Calcium compounds moistened with hydrochloric acid and placed on a platinum wire in the hottest part of a Bunsen flame impart a red color to the flame.

Calcium may be precipitated from solution as oxalate by first making the solution ammoniacal and then adding ammonium oxalate or oxalic acid. Blowpipe—on coal with soda, insoluble and not absorbed by the coal. Flame—yellow red,

improved by moistening with HCl. With borax or sodium phosphate, clear and colorless; can be flamed opaque.

Cerium.—Fuse with sodium carbonate. Treat with dilute hydrochloric acid, evaporate to dryness and bake. Take up with dilute hydrochloric acid, filter. Add ammonia to the filtrate, filter. Dissolve the precipitate in hydrochloric acid, add ammonia and oxalic acid, filter. Dissolve the precipitate in concentrated hydrochloric acid, nearly neutralize with ammonia; add 1 cc. of hydrogen peroxide and then ammonia, drop by drop, until just alkaline. When just neutral, white thorium peroxide is precipitated; when ammoniacal, the orange cerium peroxide is precipitated.

Chromium.—Chromium oxide is detected in its insoluble compounds by its characteristic green color. It forms an emerald-green head with borax or microcosmic salt. Caustic potash or soda gives a green precipitate in solutions of chromic salts. This dissolves in an excess of alkali in the cold, but is precipitated on boiling the solution. The detection of chromic acid is rendered easy by the bright-yellow color of its salts. The yellow color of the normal chromates becomes red on the addition of an acid, and again yellow when made alkaline. Blowpipe—with borax or sodium phosphate, oxidizing flame, reddish when hot, fine yellow when cold. Reducing flame, in borax, green hot and cold. In sodium phosphate, red when hot, green when cold. With soda—oxidizing flame, dark yellow when hot, opaque and light yellow cold. Reducing flame, opaque and yellowish green cold. Manganese interferes, giving a bright yellowish green with soda bead in the oxidizing flame.

Cobalt.—Ammonium sulphide produces a black precipitate (CoS) insoluble in acetic acid and in dilute hydrochloric acid. Ammonium sulphocyanate produces a beautiful blue color, $Co(CNS)_2$. With a borax bead cobalt gives the characteristic cobalt-blue color. Blowpipe—on coal, reducing flame, the oxide becomes magnetic metal. The solution in HCl will be rose-red, but on evaporation will be blue. With borax or sodium phosphate, pure blue in either flame.

Columbium.—Fuse with potassium bisulphate. Pulverize the fusion and treat it with hot water; then treat it with dilute hydrochloric acid. Digest the residue with ammonium sulphide to remove W, Sn, etc. Wash and treat again with dilute hydrochloric acid. The residue should be colorless and contain only silica and the oxides of columbium and tantalum. This residue in a bead of microcosmic salt is colorless if no columbium is present or if heated in the oxidizing flame; but if heated in the reducing flame, columbium imparts a violet color to the bead, or blue if saturated with oxide. Adding ferrous sulphate turns the bead blood red.

If, when the mixed oxides are boiled in dilute sulphuric acid with metallic zinc, the white precipitate turns intensely blue and remains so on dilution, columbium is present; if it turns bluish gray and colorless on dilution, tantalum is predominant.

Copper.—Copper can easily be detected by the reduction

to the red metallic bead on charcoal before the blowpipe. Copper compounds moistened with HCl color the non-luminous flame green. An excess of ammonia added to a nitric acid solution of copper produces an azure-blue color. With borax or sodium phosphate, oxidizing flame, green when hot, blue or green blue cold. (By repeated oxidation and reduction, the borax bead becomes ruby red.) Reducing flame, green or colorless hot, opaque and brownish red cold.

Erbium.—Erbium oxide heated on a platinum wire colors the flame distinctly green.

Gallium.—If a neutral solution of gallium chloride be warmed with zinc, gallium oxide or basic salt separates but not the metal.

Germanium.—Fuse with sulphur and sodium carbonate. Treat with hot water, filter, add a few drops of hydrochloric acid to the filtrate to precipitate white germanium sulphide. Filter and heat the residue in a current of hydrogen to reduce it to gray-black crystalline germanous sulphide. Dissolve the crystals in hydrochloric acid and pass hydrogen sulphide into the solution to precipitate reddish-brown germanous sulphide.

Glucinum.—Ammonium carbonate produces a white precipitate, $GlCO_3$, soluble in an excess of the reagent; by boiling the solution it is precipitated as a basic carbonate.

Gold.—Gold may be reduced from its ores on charcoal to a yellow malleable bead which is soluble in *aqua regia;* if the solution be dropped on filter paper and one drop of stannous chloride added, a purple-red color is produced.

Indium.—Heated on charcoal before the blowpipe it colors the flame blue, and gives an incrustation of the oxide. It slowly dissolves in hydrochloric and dilute sulphuric acids, but readily in nitric acid.

Iridium.—Ammonium chloride produces in a tolerably concentrated solution of iridium a dark-red crystalline precipitate. Iridium is distinguished from platinum by the formation of a colorless solution of potassium chloriridiate when caustic potash is added to the chloride of the metal, and on exposure to the air this colorless solution first becomes red colored and afterward blue.

Hydrogen sulphide precipitates brown iridium sulphide, which is soluble in ammonium sulphide.

Iron.—Ferrous salts with potassium ferricyanide produce a dark-blue precipitate. Ferric salts with ammonia or the fixed alkalies produce a brown precipitate. Ferric salts with potassium or ammonium sulphocyanate produce a blood-red-colored precipitate. Ferrous salts with a bead of microcosmic salt or borax are colored dark green. This color readily changes to yellow or reddish brown by oxidation. Blowpipe—on coal, with reducing flame, many compounds become magnetic. Soda assists this reaction. With borax, oxidizing flame, yellow to red hot, colorless to yellow cold. With reducing flame, bottle green. With tin on coal, violet-green. With

sodium phosphate, oxidizing flame, yellow to red hot, greenish when cooling, colorless to yellow cold. Reducing flame, red both hot and cold, greenish when cooling.

Lead.—Black precipitatate formed with hydrogen sulphide, chrome yellow with chromates. In nitric acid solution dilute sulphuric acid gives a white precipitate of lead sulphate. Blowpipe —on coal, lead is reduced in either flame to malleable metal, and yields near the assay a dark lemon-yellow coat, sulphur yellow cold, and bluish white at border. The phosphate yields no coat without the aid of a flux. With bismuth flux on plaster chrome-yellow coat, blackened by $(NH_4)_2S$. On coal, volatile yellow coat, darker hot. Flame, azure blue. With borax or sodium phosphate, oxidizing flame, yellow hot, colorless cold. Flames opaque yellow. In reducing flame, borax bead becomes clear; S. Ph. bead, cloudy.

Lithium.—In the Bunsen flame a fine carmine-red color is produced, visible if sodium is present by viewing the flame through cobalt glass. If silicon is present, make into a paste with boracic-acid flux and water and fuse in the blue flame. Just after the flux fuses the red flame will appear.

Magnesium.—To a solution of magnesium add ammonium chloride, ammonia and sodium phosphate; a white precipitate ($MgNH_4PO_4$) forms. The action is hastened by rubbing the sides of the beaker with a glass rod. Blowpipe—on coal, with soda, Mg is insoluble and not absorbed by the coal. With borax or sodium phosphate, clear and colorless; can be flamed opaque white. With cobalt solution, strongly heated, becomes a pale flesh color. (With silicates this action is of use only in absence of coloring oxides. The phosphate, arsenate and borate become violet colored.)

Manganese.—Ammonium sulphide produces a flesh-colored precipitate. A solution containing traces of manganese boiled in concentrated nitric acid with lead peroxide or sodium bismuthate and allowed to settle gives a violet-red-colored solution ($HMnO_4$). The borax bead with manganese in the oxidizing flames gives an amethyst-colored bead (with much, black or opaque) and this in the reducing flame becomes colorless or with black spots. With soda, oxidizing flame, bluish green and opaque when cold. Nitrate assists the reaction. If silicon is present, dissolve in borax, then make soda fusion.

Mercury.—Stannous chloride heated with a solution of mercury precipitates gray metallic Hg. Mercury compounds mixed with sodium carbonate and heated in a closed tube produce a gray mirror of metallic Hg. With bismuth flux, on plaster, Hg gives a volatile yellow and scarlet coat. If too strongly heated the coat is black and yellow. On coal Hg gives a coat faint yellow at a distance. In matrass gives mirror-like sublimate, which may be collected in globules. (Gold leaf is whitened by the least trace of mercury vapor.)

Molybdenum.—To a strong nitric acid solution of molybdenum add nearly enough ammonia to neutralize the acid and

then add a few drops of sodium phosphate solution. A bright-yellow, crystalline precipitate forms when the solution is warmed. A hydrochloric or sulphuric acid solution of molybdenum, to which zinc or stannous chloride is added, turns first blue, then green, and finally brown. On coal, with oxidizing flame Mo gives a coat, yellowish when hot, white when cold, crystalline near assay; in reducing flame the coat is turned in part deep blue, in part copper red. Its Bunsen-burner flame is yellowish green. With borax, oxidizing flame, yellow when hot, colorless when cold. Reducing flame, emerald green.

Neodymium.—The didymium salts are violet and are identified by a characteristic absorption spectrum.

Nickel.—Potassium cyanide produces a bright-green precipitate, $Ni(CN)_2$. When nickel compounds are heated with reducing agents before the blowpipe, an infusible magnetic powder is produced. If this powder is dissolved in a drop or two of dilute nitric acid and evaporated to complete dryness, a characteristic green stain is obtained which becomes yellow on further heating. Nickel compounds color the borax bead brownish yellow in the oxidizing flame, the bead becoming gray and opaque in the reducing flame, owing to the separation of metallic nickel. Nickel is precipitated in alkaline solution by ammonium sulphide, which dissolves in an excess of ammonium sulphide forming a dark-colored solution.

Osmium.—It is dissolved in fuming nitric acid, or by fusing with sodium hydroxide and potassium nitrate and then treating with nitric acid and distilling. Osmic oxide (OsO_4), which sublimes at a moderately low temperature, passes over and condenses as a colorless crystalline mass. The osmic oxide has an odor similar to chlorine and is poisonous.

Palladium.—Dissolves in nitric acid or *aqua regia*. Potassium iodide added produces a black precipitate, palladous iodide (PdI_2), soluble in an excess of the reagent but not soluble in water, alcohol, or ether. Mercuric cyanide, $Hg(CN)_2$, produces a yellowish-white gelatinous precipitate, $Pd(CN)_2$, which, on ignition, leaves the spongy metal. See also special articles on palladium determination on p. 264.

Platinum.—When heated with sodium carbonate on charcoal, gray spongy metal is reduced. This, rubbed on a mortar with a pestle, gives a metallic luster and is insoluble in any single acid. See also special articles on platinum determination on p. 264.

Potassium.—A solution of H_2PtCl_6 added to concentrated solutions of potassium gives a yellow precipitate K_2PtCl_6. In the Bunsen flame potassium gives a violet color, visible if sodium also is present if viewed through cobalt glass.

Praseodymium.—See Neodymium.

Radium.—To the Bunsen flame a radium salt imparts an intense carmine-red color. Radium rays discharge a charged electroscope and may be used for making photographs on ordinary X-ray plates.

Rhodium.—Before the blowpipe on charcoal with sodium carbonate the salts of rhodium are reduced to the metal, which

is insoluble in *aqua regia*, but may be dissolved by fusing it with potassium pyrosulphate and then treating the fusion with water. By adding to this solution potassium hydroxide and a little alcohol the brown rhodium hydroxide is formed.

Rubidium.—A solution of H_2PtCl_6 produces a white crystalline precipitate, Rb_2PtC_6, which is less soluble than the corresponding potassium salt and more soluble than the cæsium salt. The flame test gives a color similar to the cæsium test.

Ruthenium.—Ruthenium is practically insoluble in all acids and in *aqua regia*. Fuse it with potassium hydroxide and potassium nitrate. The resulting K_2RuO_4 heated with NaCl in a current of chlorine yields soluble K_2RuCl_6. The greenish-black fusion treated with water yields an orange-yellow solution, which stains the skin black.

Scandium.—A hydrochloric acid solution of scandium treated with solid sodium silicofluoride and boiled 30 min. gives a precipitate containing scandium free from the rare earth metals.

Silver.—When fused with sodium carbonate on charcoal before the blowpipe, a bright metallic silver bead is produced, which may be dissolved in nitric acid and precipitated from the solution by hydrochloric acid as a curdy precipitate of silver chloride, or, if only a trace of silver is present, as a mere opalescence.

Sodium.—To a neutral or weakly alkaline solution add potassium pyroantimonate, $K_2H_2Sb_2O_3$, and a heavy white crystalline precipitate, $Na_2H_2Sb_2O_3$, is quickly formed by rubbing the sides of the beaker with a glass rod. Solutions of sodium on a platinum wire in a Bunsen flame give a yellow color.

Strontium.—Solutions on a platinum wire color the Bunsen flame carmine red, improved by moistening with HCl. Strontium sulphate is less soluble than calcium sulphate, but more soluble than barium sulphate. If barium is present the flame turns brownish yellow. The lithium flame is unaffected by addition of barium chloride.

Sulphur.—Fuse on coal with soda and a little borax in the reducing flame and place melt on a bright silver coin. Moisten, crush, and let stand. In presence of sulphur the coin will turn brown or black.

Thallium.—Dissolve in dilute acid, add H_2S, filter. Add to the filtrate ammonium sulphide and filter. If thallium is present in the precipitate it will color the Bunsen flame emerald green.

Thorium.—Fuse in a platinum crucible with sodium carbonate. Cool, dissolve in water and hydrochloric acid. Evaporate to dryness and bake. Take up with dilute hydrochloric acid, filter. Add ammonia to the filtrate, filter. Dissolve the precipitate in hydrochloric acid; reprecipitate with oxalic acid, filter, ignite the residue. Dissolve in hydrochloric acid. Evaporate to dryness. Take up with water. Add an excess of sodium thiosulphate and boil to precipitate.

Tin.—Mercuric chloride added to a solution of a stannous

salt precipitates white mercurous chloride. A trace of stannous chloride in solution added to a solution of gold chloride precipitates finely divided gold, brown by transmitted light and bluish green by reflected light. Metallic zinc precipitates tin from solution as a spongy mass, which adheres to the zinc. Heat the ore on charcoal with sodium carbonate or potassium cyanide; a metallic bead is produced which is coated with white oxide when the flame is removed. Cassiterite in lumps in a test-tube with metallic zinc and dilute sulphuric acid is soon coated with metallic tin.

Titanium.—Titanium sulphate with hydrogen peroxide in a slightly acid solution produces an orange-red color, or a clear yellow with small amounts of titanium. Vanadic acid with hydrogen peroxide produces a similar effect. Tin or zinc in hydrochloric acid solutions of titanium produces a violet color due to Ti_2Cl_2.

Tungsten.—Treat with hydrochloric and nitric acids (4:1) and take to dryness, wash by decantation, add dilute hydrochloric acid and metallic zinc, aluminum, or tin and shake; a fine blue coloration or precipitate is produced, W_2O_5; the color disappears when diluted with water. Fuse in platinum with potassium bisulphate, digest with a solution of ammonium carbonate, filter, add to the filtrate a few drops of $SnCl_2$ solution, acidify with hydrochloric acid, warm gently; a fine blue color is produced. The microcosmic salt bead made in the reducing flame is clear blue; if iron is also present, the bead will be red brown. In the oxidizing flame the bead is colorless.

Uranium.—Potassium ferrocyanide produces a brown precipitate, in dilute solution a brownish-red coloration. The borax (or microcosmic salt) bead is yellow in the oxidizing flame and green in the reducing flame.

Vanadium.—Vanadium compounds can be dissolved by a treatment with acids or alkalies. The hydrochloric acid solution assumes a bright blue color on addition of zinc. A solution of hydrovanadic sulphate cannot be distinguished in color from one of copper sulphate when sufficiently diluted with water, but, of course, does not become colorless in the presence of metallic iron. Solutions of certain vanadates also closely resemble solutions of the chromates. For instance, a solution of the tetravanadate of potassium, $K_2V_4O_{11}$, does not differ in appearance from one of potassium dichromate. They may, however, be distinguished from one another, since the vanadate solution becomes blue and the chromate assumes a green color on deoxidation. When a solution of vanadic acid or an acid solution of an alkali vanadate is shaken up with ether containing hydrogen peroxide, the aqueous solution assumes a red color like that of ferric acetate. This reaction serves to detect one part of vanadic acid in 4000 parts of the liquid. Chromic acid does not interfere with the reaction.

Yttrium.—Extract the yttrium in the manner described under Cerium and separate it from the other rare earths in a solution of their sulphates by adding a saturated solution of

potassium sulphate. Yttrium sulphate is soluble; the others are not.

Zinc.—Ammonium sulphide precipitates ZnS. Potassium ferrocyanide produces a white precipitate, $Zn_2Fe(CN_6)$. Before the blowpipe on charcoal with sodium carbonate, a coating of oxide is produced which is yellow while hot and white when cold. With cobalt nitrate on charcoal an infusible green mass is produced.

Zirconium.—Treat with dilute sulphuric acid (2:1), filter, add ammonia to the cold filtrate, filter; wash, dissolve the precipitate in hydrochloric acid, evaporate to dryness. Take up with a little water and add to the cold saturated solution hydrochloric acid, drop by drop; if zirconium is present, the oxychloride will be precipitated. Heat to dissolve the precipitate. Cool and after some time fine silky needles of $ZrOCl_2 + 8H_2O$ will precipitate.

DETERMINATION OF PLATINUM, PALLADIUM AND GOLD[1]

Scorify the lead buttons from two or more ½-a.t. crucible fusions together, adding at least six times as much silver as the combined weight of the Pt, Pd and Au present, and cupel *hot*. In rich materials such as slimes or concentrates, two ½-a.t. fusions suffice, but low-grade ores may require 10 or more ½-a.t. fusions combined for each determination.

Part the silver beads with HNO_3 (1:6), followed by stronger parting acid (1:1) and wash with water as usual. All Pd goes into solution, together with considerable Pt. The residue consists of Au plus some Pt. Dissolve residue in strong *aqua regia* and reserve the solution (solution *A*). Precipitate the silver in the nitric-acid solution—containing Ag, Pd and some Pt—with HCl. Practically all the Pt will remain in solution; but the precipitated AgCl is pink in color and contains considerable Pd. Filter off the AgCl, scorify and cupel it and part again with HNO_3 (1:6); all should dissolve. Reprecipitate the Ag with HCl. The liquid now contains most of the remaining Pd, but some is co-precipitated with AgCl. Filter off the AgCl and add the filtrate to the first filtrate from AgCl. Again scorify and cupel the silver chloride, dissolving the silver in nitric acid as before and reprecipitating the silver as chloride. In most cases the filtrate from this silver chloride contains all the remaining Pd. If, however, the AgCl is distinctly pink, another separation must be made.

Unite all filtrates from AgCl precipitations and evaporate to small bulk, adding the *aqua-regia* solution of the Au and Pt (solution *A*). The liquid now contains all the Au, Pt and Pd present in the original ore, together with traces of Ag due to solubility in AgCl in excess of HCl, and also traces of Pb gathered from the lead retained in the silver buttons from the several recupellations.

[1] From an article by A. M. Smoot, *Eng. and Min. Journ.*, Apr. 17, 1915.

Evaporate the liquid to dryness on the steam bath; take up with dilute HCl (1:3) and evaporate again to dryness; take up with five drops of HCl and 40 cc. H_2O. Pay no attention to any insoluble residue of AgCl or $PbCl_2$.[1] Precipitate gold by adding, say, 3 grams of oxalic acid to the solution and boiling it. Let stand over night and filter off the Au. If Pt and Pd are high, it is necessary to redissolve the Au in *aqua regia*, evaporating with HCl to dryness and repeating the oxalic-acid precipitation, uniting the filtrate with that from the first gold precipitation. Burn the filter containing the gold and scorify it with six times its weight of silver and a little test lead; cupel, part and weigh the gold as usual.

To the oxalic-acid filtrates from Au add 5 cc. of HCl and make volume up to 150 cc.; heat to boiling and precipitate Pt and Pd with a rapid current of H_2S in *hot* solution, passing the current of gas for some time and keeping the solution hot during precipitation. Filter and wash the Pt and Pd sulphides with H_2S water containing a little HCl. Wash the precipitate from the filter with a fine water jet into an original beaker; spread the filter paper (which will contain a small amount of precipitate impossible to wash off) with the precipitate side down over the lower side of a watch-glass cover. Add *aqua regia* to the precipitate in the beaker and place the cover on the beaker; warm gently to dissolve the Pt and Pd sulphides. The fumes arising from the acid dissolve the traces of Pt and Pd adhering to the filter paper. When solution is complete and the filter paper is white, remove the watch-glass cover and wash the paper with hot dilute HCl thrown against it in a fine stream.

Evaporate the *aqua-regia* solution to dryness, take up the residue with HCl and evaporate again to dryness to remove all HNO_3. Take up the residue with two or three drops of HCl and about 2 cc. of H_2O. The solution is usually perfectly clear, but it may be slightly cloudy owing to the presence of a little AgCl in it. No attention need be paid to this, however. Add 5 to 10 cc. of a saturated solution of NH_4Cl, stir well and allow to stand over night. Platinum is precipitated as ammonium-platinum chloride—$(NH_4)_2PtCl_6$. Filter and wash the precipitate with 20 per cent. NH_4Cl solution. All Pd passes into the filtrate which is reserved (solution *B*). Dissolve the Pt precipitate in boiling hot 5 per cent. H_2SO_4; heat the liquid to actual boiling and precipitate with H_2S as before, filtering and washing with H_2S water. Burn the filter and precipitate at a low temperature in a scorifier; add six times as much Ag as Pt, scorifying with lead, cupel and part the silver bead containing the platinum with H_2SO_4; decant off the silver solution and

[1] In materials rich in palladium the small amount of AgCl + $PbCl_2$ may be distinctly pink in color and retain weighable quantities of Pd. If this is the case, the Pd may be recovered in the solution from the nitric acid parting of the gold. To do this, precipitate the silver in this liquid by adding HCl, filter off the silver chloride and evaporate the filtrate to dryness. Take up with a drop of HCl and a little water, let stand over night and filter through a very small filter. This liquid may be added to solution B before precipitating palladium with glyoxime.

wash once with strong H_2SO_4, followed by 50 per cent. H_2SO_4 until practically all silver is washed away; finally wash with water, anneal and weigh. A minute quantity of Ag is retained with the platinum, but it can usually be neglected. In very important work where the amount of platinum is large dissolve in *aqua regia*, evaporate the solution to dryness, take up with a drop of HCl, dilute largely with water and let the AgCl settle over night; filter on a small paper, cupel it with a little sheet lead and deduct the weight from the weight of platinum. This refinement need not be considered in materials running less than 15 or 20 oz. to the ton.

It may seem an unnecessary step to precipitate the platinum as sulphide, scorify it with silver and part it as described in the foregoing. General practice has been to ignite the ammonium-platinum-chloride precipitate and weigh the metallic residue. When this is done, however, there is danger of losing considerable platinum, which is carried away mechanically during the decomposition of the compound; furthermore, it is extremely difficult (if not impossible) to collect the finely divided residue for weighing, and the precipitate invariably contains lead and silver. Precipitation as sulphide, scorification and cupellation with excess silver and parting with sulphuric acid overcome the difficulties inherent in handling the ammonium precipitate.

The palladium is all contained in the filtrate and washings from the platinum-ammonium-chloride precipitates (solution *B*). Add to this solution at least seven times as much dimethylglyoxime as there is Pd present (in any case, at least 0.1 gram glyoxime). The precipitant should be dissolved in a mixture of two-thirds strong HCl and one-third water. Dilute the liquid to 250–300 cc., heat on a steam bath for half an hour and let stand over night. Pd is precipitated as a voluminous, yellow, easily filtered glyoxime compound $(C_8H_{14}N_4O_4)_2Pd$, containing, when dried at 110°C., 31.686 per cent. of Pd. Filter the Pd precipitate on a weighed Gooch crucible and wash it first with dilute HCl, half and half, then with warm water and finally with alcohol; dry it at 110° to 115°C. and weigh. The disadvantage of weighing palladium on a Gooch crucible is overcome—at least to some extent—by the fact that the Pd compound contains a relatively small amount of Pd—less than one-third of its weight. This compound may also be weighed on carefully counterpoised papers; but it is better to use Gooch crucibles, if they are available, because of the relatively strong acid which is required for washing. The object in using half-and-half hydrochloric acid as a wash liquid is to dissolve out any excess of the glyoxime precipitant. This is easily soluble in moderately strong HCl, but is substantially insoluble in water.

DETERMINATION OF SILVER IN ORES AND CONCENTRATES CONTAINING PLATINUM AND PALLADIUM

Make the usual crucible fusion on one-quarter, one-half or full assay ton, according to the amount of silver present. Instead of cupeling the lead button, hammer it free from slag and dissolve it in dilute nitric acid. Most of the silver passes into solution together with palladium, and perhaps a trace of platinum; but gold and most of the platinum remain insoluble. The gold and platinum retain an appreciable proportion of silver which cannot be washed out. Filter out the insoluble residue and wash it thoroughly with hot dilute nitric acid, followed by hot water. Scorify the residue once more with a little lead and dissolve the lead button as before, filtering into the beaker containing the first filtrate. In this liquid precipitate the silver as AgCl by adding standing NaCl in sufficient quantity; stir well, and if the amount of silver is small, add about ½ cc. of strong H_2SO_4 to form a precipitate of lead sulphate. Let the silver chloride, or the silver chloride plus lead sulphate, settle over night or until the supernatant liquid is clear; filter through double filter papers; ignite and scorify the residue of silver chloride with test lead.

If the amount of palladium contained in the sample is small, the silver bead obtained by cupeling the lead button obtained by scorifying the silver chloride may be considered as sufficiently pure for ordinary purposes. It contains, of course, some palladium, and in accurate silver determinations the lead button from the first silver-chloride precipitation should be redissolved and the silver reprecipitated, filtered and scorified as before. The amount of palladium retained after the second precipitation and scorification is so small as to be negligible.

SCHEME FOR QUALITATIVE ANALYSIS OF HEAVY METALS AND ALKALINE EARTHS

(The material is either in solution or is capable of being readily dissolved.)

(*A*) Slightly acidulate solution with HCl. It is best to take only a small portion of the solution, and if a precipitate forms, see whether it redissolves in more acid. If it does, it indicates Sb or Bi. Permanent precipitate shows Ag, Pb, or Hg (ous). Filter precipitate (*B*) and reserve solution (*C*).

(*B*) Wash with hot water, and add $K_2Cr_2O_7$ solution to filtrate. Heavy yellow precipitate shows lead. Wash residue (*B*) with NH_4OH, and acidulate filtrate with HNO_3. Precipitate shows Ag. Blackening of filter paper shows Hg (ous).

(*C*) Pass in H_2S until precipitate coagulates. Precipitate may be As (yellow), Sb (orange), Sn'' (brown), Sn'''' (yellow), Hg' or Hg'' (black), Bi (brown), Cd (yellow), Pb (black), Cu (black). Filter, giving precipitate (*D*) and solution (*E*).

(*D*) Warm with ammonium polysulphide and filter. Fil-

trate (*G*) may contain As, Sb, Sn, and traces of Cu. (Also Au, Ir, Se, W, Pt, Te, V, of the rare elements.) Precipitate (*E*) contains Hg, Bi, Cd, Pb, Cu.

(*G*) Throw down precipitate from $(NH_4)_2S_2$ solution with HCl. Leach precipitate with ammonium carbonate. Arsenic dissolves. Filter. Add HCl to filtrate to faint acidity. Pass in H_2S. Yellow precipitate shows arsenic. (May be confirmed by MARSH test.) Dissolve remaider of precipitate *E* in strong HCl. Dilute and add metallic zinc in contact with a small piece of platinum. Precipitate of metallic tin and antimony forms. Treat with HCl and filter. To filtrate add $HgCl_2$ solution. White to gray precipitate of Hg_2Cl_2 shows tin. Treat residue from extraction with *aqua regia*, boil off excess Cl and HNO_3, and pass in H_2S. An orange precipitate of Sb_2S_5 *confirms* the presence of antimony, already indicated by a blackening of the platinum.

(*F*) Heat residue from ammonium polysulphide leaching with dilute (10 per cent.) HNO_3 and filter. Heat residue with concentrated HNO_3, dilute and filter, combining the two filtrates. The precipitate (*H*) remaining consists of HgS and S. The filtrate (*I*) contains Cd, Bi, Cu, Pb.[1] (If the original treatment is made with concentrated HNO_3 all of the PbS may be oxidized to $PbSO_4$ and remain with the mercury. PbS is soluble in 10 per cent. HNO_3 according to the equation $PbS + 2HNO_3 = Pb(NO_3)_2 + H_2S$).

(*H*) Dissolve precipitate in *aqua regia*. Boil off excess of Cl and HNO_3 and add $SnCl_2$. A white to gray precipitate confirms presence of mercury, probably already indicated by the black residue from the HNO_3 leaching.

(*I*) Add a few drops of H_2SO_4 to solution. White precipitate indicates lead. Filter, getting precipitate (*J*) and solution (K).

(*J*) Treat precipitate on filter with hot ammonium acetate and filter, adding $K_2Cr_2O_7$ to filtrate. Chrome-yellow precipitate confirms presence of lead.

(*K*) Evaporate to small bulk, add about eight times bulk of alcohol, warm, and filter (to ensure removal of *all* lead). Evaporate off alcohol on sand bath and make strongly ammoniacal. White precipitate indicates Bi. Blue solution indicates Cu. The blue may be so intense as to mask the $Bi(OH)_3$ precipitate. Filter and wash, and treat filter paper with strong HCl, catching strong HCl solution in a beaker. Dilute largely. White precipitate shows Bi. Take blue copper solution and add KCN solution until blue color just disappears and pass in H_2S. Bright-yellow precipitate indicates Cd.

(*E*) Boil off all H_2S from the filtrate from the H_2S precipitation, making sure finally that it is all gone by adding a few drops of HNO_3 and boiling. If organic acids, tartaric, citric, or the like are present, it is best to destroy them by evaporating almost to dryness and adding some concentrated

[1] Pd and Os belong in the H_2S group of metals whose sulphides are insoluble in $(NH_4)_2S_2$.

H_2SO_4 and fuming HNO_3. Test a little of the solution for phosphoric acid by means of ammonium-molybdate solution in nitric acid. If a yellow precipitate shows phosphates, evaporate to a thick soup, and add a little tin and nitric acid and boil until action ceases. Dilute, filter, and repeat. The phosphorus is removed as stannous phosphate, all but traces of the tin remain undissolved as metastannic acid. If only traces of the further groups of metals are being looked for, boil off all the nitric acid with repeated additions of HCl, throw out the last of the tin with H_2S, filter, then boil off the H_2S and remove the last traces of it with HNO_3, as above specified. If phosphorus is not present, all of this is unnecessary. Add a little NH_4Cl and make the solution ammoniacal. Fe, Al and Cr are precipitated[1] (*L*). Boil off excess of ammonia, filter; solution (*M*) contains Co, Mn, Ni and Zn and the alkaline earths and alkalis.

(*L*) Leach precipitate with hot KOH solution. Make leachings acid with HCl and add ammonia. White flocculent precipitate indicates alumina. Dissolve half of original precipitate with HCl and add K_4FeCy_6. Precipitate of Prussian blue confirms presence of iron, probably already indicated by red color of precipitate. Take the other half of the precipitate and fuse with sodium carbonate and sodium nitrate. A yellow melt indicates sodium chromate. Dissolve melt in water, acidify with acetic acid and add a drop of lead-acetate solution. Precipitate of lead chromate confirms presence of chromium, probably already indicated by a greenish hydroxide precipitate or the yellow melt.

(*M*) Pass in H_2S into solution. Mn, Zn, Co, Ni precipitate. Filter. Filtrate (*N*) contains alkalies and alkaline earths. Treat precipitate with cold dilute HCl. Mn and Zn dissolve. Add KOH in excess. Filter, acidify filtrate with acetic acid and pass in H_2S. A white or nearly white flocculent precipitate confirms the presence of Zn. Take the precipitate from the KOH precipitation and fuse with Na_2CO_3 and $NaNO_3$. A green melt shows manganese. Take the residue insoluble in HCl and touch a borax bead to it and heat. A bead, violet when hot, blue when cold, shows cobalt. A gray bead (cold) shows Ni only, but this is easily masked by cobalt blue. So if the bead is blue, dissolve the residue in *aqua regia*, evaporate to soup, dilute, and add KCN until the precipitate first formed redissolves. Heat solution gently, add a little NaOH, then Br (*under a hood*). A black precipitate shows nickel.

(*N*) Boil until H_2S odor becomes faint, add NH_4OH and $(NH_4)_2CO_3$ and warm slightly. Ba, Sr, and Ca precipitate. Filter and dissolve precipitate in HCl. Add H_2SO_4 to part of the solution. Precipitate indicates Ba or Sr or both. To another part of the solution add K_2CrO_4. An immediate precipitate of a pale yellow color shows Ba. In the filtrate Sr can be

[1] The hydroxide precipitate will carry down As, Sb, Se, Te, Sn, P and Ti if they are present, which reaction affords an easy way to concentrate these elements from a large bulk of copper in exact copper analysis.

determined by the reddish color given a Bunsen burner flame, while Ca can be precipitated as calcium oxalate (white) in ammoniacal solution. Calcium colors a Bunsen flame reddish yellow, and Ba a vivid green.

(*O*) Add ammonium- or sodium-phosphate solution to the filtrate from the Ba, Ca, Sr precipitation. Stir, cool, and allow to settle over night. Granular white precipitate shows **Mg.**

Qualitative Tests for Acids[1]

The acid-radicals cannot be advantageously precipitated in groups, and the members separated and identified as with the metals. They are usually detected in the course of analysis by special tests. They may, however, be arranged in groups of such acid-radicals as resemble one another. A consideration of the metals present, in case the material is in solution, will often rule out many acids as possibilities at once.

The acids may be arranged as follows:

Group I.—Acids which are precipitated by $AgNO_3$ in presence of nitric acid.

Hydrosulphuric acid	H_2S
Hydrochloric acid	HCl
Hydrobromic acid	HBr
Hydriodic acid	HI

Group II.—Acids whose salts deflagrate on charcoal.

Nitric acid	HNO_3
Chloric acid	$HClO_3$

Group III.—Acids which cannot be classified.

Boracic acid	H_3BO_3
Carbonic acid	H_2CO_3
Chromic acid	H_2CrO_4
Hydrofluoric acid	HF
Phosphoric acid	H_3PO_4
Silicic acid	H_4SiO_4
Sulphuric acid	H_2SO_4
Arsenic acid	H_3AsO_4
Hydrocyanic acid, acetates	HCN

GROUP I

H_2S.—$AgNO_3$ gives a black pp. of Ag_2S insoluble in dilute acids.

Lead acetate—a black pp. of PbS insoluble in dilute acids.

Dilute HCl—many sulphides when heated with dilute HCl evolves H_2S, which blackens paper moistened with lead acetate. If much H_2S is present, there will be the characteristic odor present, but do not smell the gas coming off unless you are sure no cyanides are present. It is safer to have some one else smell it, anyway.

[1] James Park, "A Text-Book of Practical Assaying," with some original additions.

HCl.—$AgNO_3$—a white pp. of AgCl at first white, turns violet on exposure to light. Readily soluble in ammonia and KCN. Insoluble in dilute nitric acid.

Lead acetate—a white pp. of $PbCl_2$ soluble in hot water.

Strong H_2SO_4—when heated with dry chlorides causes evolution of HCl gas, chlorides of Hg and Sn excepted. Bromides, iodides, fluorides, cyanides, carbonates, sulphides, sulphites, thiosulphates and acetates also give off characteristic gases during this test.

$MnO_2 + H_2SO_4$—when mixed with a chloride causes evolution of chlorine, which bleaches wet litmus paper or a green leaf. Iodine and bromine are also evolved by this means. The colors are characteristic.

HBr.—$AgNO_3$—a yellowish-white pp. of AgBr; sparingly soluble in ammonia but readily in KCN. Insoluble in dilute nitric acid. Phosphates also give a yellow precipitate. Test for phosphoric acid with ammonium molybdate in HNO_3 solution.

Lead acetate—a white pp. of $PbBr_2$.

Strong H_2SO_4—with a dry bromide causes evolution of HBr vapors.

$MnO_2 + H_2SO_4$—causes evolution of Br, which turns starch paper yellow.

Chlorine water or HCl + two drops of NaClO, when added, drop by drop, to a solution of a bromide liberates Br, which colors solution orange red. Avoid excess of Cl, as it destroys color. When a portion is warmed, reddish-brown vapors are given off. If three drops of CS_2 are added, the Br will sink to the bottom.

HI.—$AgNO_3$—a yellowish-white pp. of AgI. Sparingly soluble in ammonia; readily in KCN. Insoluble in dilute nitric acid.

Lead acetate—bright yellow pp. of PbI_2.

Chlorine water—reacts for iodine, giving a brown solution and violet vapors. To a portion add starch solution, an intense blue is produced.

GROUP II

Nitric Acid (Nitrates)[1]

Dry Reactions.—1. If a nitrate is heated on charcoal it deflagrates, the charcoal burning at the expense of the O of the nitrate. Nitrites, chlorates, chromates, manganates and permanganates also give this reaction.

2. If a mixture of a nitrate and KCN powder be heated on platinum foil, deflagration takes place. This is a delicate test.

Wet Reactions.—1. Strong H_2SO_4 heated with nitrates causes evolution of fumes of nitric acid. Nitrites give this reaction.

2. Mix sol. of a nitrate with strong sol. of $FeSO_4$. Hold test-tube in a slanting position and pour strong H_2SO_4 down to

[1] Nitrites also give most of these reactions.

bottom. A purple or brown color will mark the plane of contact of the fluids. Nitrites also give this and the following reaction.

3. Copper filings and H_2SO_4 heated with a nitrate liberate NO, which becomes peroxidized to NO_2 on contact with the air.

4. A sol. of indigo boiled with HCl and a sol. of a nitrate is decolorized. Not characteristic, as chlorine reacts the same.

5. A little brucine dissolved in H_2SO_4 when added to a sol. of a nitrate gives a fine red color. This is a very delicate test.

6. Free nitric acid may be detected by evaporating to dryness with quill-cuttings. These will be colored yellow.

It gives with $FeSO_4$ a brown ring; and with copper filings or foil a reddish-brown gas, NO_2, and a blue color.

The most delicate test for nitrates is to take 2 or 3 c.c. of the solution in HCl, add 12 drops of a solution of diphenylamine in sulphuric acid, then run in H_2SO_4 below the mixture. A faint blue will be given by 1 part in 1,000,000 of HNO_3.

Chloric Acid (Chlorates)

Dry Reactions.—1. Chlorates when heated on charcoal deflagrate far more violently than nitrates. So do perchlorates.

2. Heated on charcoal with KCN, chlorates detonate violently. Use only small quantities in this experiment.

Wet Reactions.—1. A few drops of H_2SO_4 added to a small quantity of a chlorate liberate chlorine peroxide (ClO_2), which colors the H_2SO_4 intensely yellow, and has a strong odor of Cl and a greenish color. This experiment should be tried in a watch-glass *without heat*, as an explosion might take place.

2. If a cold sol. of indigo is added to a cold sol. of a chlorate till distinctly blue, and some H_2SO_4 then poured in and shaken, the blue color of the indigo is at once destroyed. Chlorites, perchlorates, and hypochlorites also give this reaction.

3. If a chlorate is mixed with Na_2CO_3 and ignited, O_2 is given off and a chloride remains. On dissolving the residue, acidifying with nitric acid, and adding silver nitrate, a white pp. of AgCl is formed.

GROUP III

Boracic Acid

Dry Reactions.—1. Boric acid tinges the Bunsen flame green.

2. Pour some methylated spirits on finely powdered borax in a porcelain dish; add a little H_2SO_4; mix and ignite; the flame will show a green edge.

Wet Reactions.—1. If a sol. of an alkaline borate is mixed with HCl to slight but distinct acid reaction, and a strip of turmeric paper is *half dipped* into it and then dried at 212°F. (100°C.), the dipped half will show a peculiar red color—very delicate. Sodium carbonate turns this to a dark blackish-green, and HCl will restore the color.

Carbonic Acid

Wet Reactions.—1. Almost any acid when poured on a carbonate in a test-tube causes effervescence due to rapid evolution of CO_2. When conducted into lime-water this gas causes a pp. of $CaCO_3$, which is sol. in large excess of the gas. Cyanides, sulphites, tellurides, selenides, sulphides, and thiosulphates also effervesce. Be careful about inhaling these gases.

Chromic Acid

Dry Reactions.—1. Compounds of chromic acid give an emerald-colored bead with borax on platinum loop in both outer and inner blowpipe flames.

Wet Reactions.—1. H_2S added to an acidified sol. of a chromate produces a green coloration due to reduction of the chromic acid [CrO_3]. A white precipitate of sulphur is formed at the same time.

(Readily oxidizable substances deoxidize $K_2Cr_2O_7$ with production of a chromic salt; the color of the solution at the same time changes from orange red to bright green.)

2. H_2O_2 or BaO_2 if added to a *cold* acidified sol. of a chromate produces an intense blue coloration, which becomes fixed if *ether* is *first* added and the liquid well shaken after adding the peroxide. The ether assumes and retains the blue color. A few drops of HNO_3 are useful. This is an extremely delicate and characteristic test.

3. $BaCl_2$ gives a light yellow pp. of $BaCrO_4$, sol. in HCl and HNO_3.

4. $AgNO_3$ gives a dark purple-red pp. of Ag_2CrO_4, sol. in KNO_3 and NH_4OH.

5. $Pb(C_2H_3O_2)_2$ gives a yellow pp. of $PbCrO_4$, sol. in KOH, but insol. in $C_2H_4O_2$. This precipitate, "chrome yellow," is very characteristic.

6. If insoluble chromates are fused with Na_2CO_3 and KNO_3, alkaline chromates will be formed, which are soluble in water.

Hydrofluoric Acid

The ordinary tests for a fluoride depend on the liberation of HF, which is allowed to etch glass.

1. If strong H_2SO_4 is warmed with a little finely powdered CaF_2 in a test-tube, HF is liberated.

2. Cover the convex side of a watch-glass with melted paraffin or wax. Trace lines near the middle of the glass with the point of a penknife so as to remove the wax from these parts, but not to scratch the glass. Place the prepared glass on the top of a platinum crucible containing a little finely powdered CaF_2 and some strong H_2SO_4. Pour a few drops of water into the watch-glass to keep it cool, and gently heat the bottom of the crucible. Allow to stand for 20 minutes. Melt off wax, and on the clean surface the etched lines will be visible. If small

traces of a fluoride were present, the tracing will become visible by breathing on the cold surface of the glass.

This reaction fails when there is too much SiO_2 present, as the H_2SO_4 then liberates SiF_4 instead of HF.

SiF_4 does not etch glass, but produces white fumes in moist air; when these fumes are conducted into water a colorless flocculent pp. of gelatinous silica is separated.

$$H_4SiO_4 = SiO_2 + 2H_2O$$

3. $CaCl_2$ when added to the solution of a fluoride gives an almost transparent gelatinous pp. of CaF_2, which becomes more visible when the liquid is heated or when ammonia is added.

Phosphoric Acid

Wet Reactions.—1. $MgSO_4$ solution (to which ammonium chloride has been added and then a little ammonia) gives with the solution of a phosphate a white crystalline pp. of magnesium ammonium phosphate ($MgNH_4PO_4 + 6H_2O$) which rapidly settles. This pp. is insol. in NH_4OH, but is readily sol. in acids, even $C_2H_4O_2$. If very little phosphate is present, the pp. often appears only after the solution has been warmed and allowed to stand.

2. Silver nitrate throws down from neutral solutions a light yellow pp. of Ag_3PO_4, readily soluble in nitric acid and ammonia.

3. The solution of ammonium molybdate in nitric acid gives in the *cold* a finely divided yellow pp. which settles rapidly. With small quantities of a phosphate, a few hours must be allowed for the reaction, and the liquid may be warmed gently, but not above 40°C. (104°F.). Not more than an equal volume of the fluid to be tested should be added to the molybdate. Large quantities of HCl interfere with the precipitation.

The pp. after subsiding may be separated by filtering, washed with ammonium molybdate solution, then dissolved in ammonia, and, by adding NH_4Cl and $MgSO_4$ as in (1), the pp. of $MgNH_4PO_4 + 6H_2O$ may be obtained.

The solution to be tested must not be alkaline to test paper, but should be made distinctly acid with HNO_3. It should then be added in *small quantities* only to some NH_4HMoO_4 sol. in a test-tube, more being added if no yellow pp. forms after a few minutes, when the liquid may be gently warmed.

Arsenates

The pps. found in (1) and (3) with a phosphate are precisely the same as those formed when an arsenate is present. $AgNO_3$ gives with an arsenate a brown pp.; with a phosphate a yellow pp.; and ammonium molybdate solution gives a pp. with an arsenate only after boiling instead of gently heating as with a phosphate. It is also possible to remove the arsenic with H_2S in HCl solution before making confirmatory tests for phosphates.

Silicic Acid

Dry Reaction.—1. If a fragment of silica or a silicate is heated in a bead of microcosmic salt, it remains undissolved and floats about in the bead as a more or less transparent mass, which retains its original shape. In the case of a silicate the bases dissolve out.

Wet Reactions.—2. NH_4Cl produces in not too dilute solutions of alkaline silicates a pp. of hydrated SiO_2.

3. The solutions of alkaline silicates are decomposed by all *acids*, the SiO_2 separating as the gelatinous hydrate. The acid should be added drop by drop and the solution stirred.

Sulphate Group

REMARKS.—Sulphates are the only commonly occurring salts which give with $BaCl_2$ a pp. insoluble in boiling HCl. (Selenates also give a pp. of $BaSeO_4$ with $BaCl_2$, but it dissolves on boiling with strong HCl for some time.)

Tests for Sulphates (SO_3, and a Base)

Wet Reactions.—1. All solutions of the sulphates give with $BaCl_2$ a white pp. of $BaSO_4$ which is insoluble in all acids.

2. If a sulphate or *any* solid substance containing sulphur is mixed with pure solid Na_2CO_3 and fused on charcoal in the inner reducing blowpipe flame, it will yield Na_2S.

Detach the cold fused mass with the point of a knife, place a portion on a bright silver coin, and moisten with H_2O. Allow to remain a short time, and then rinse off; a black stain of Ag_2S will be seen upon the coin, if sulphur is present.

3. Lead acetate produces a heavy white pp. of $PbSO_4$, which dissolves readily in hot strong HCl, or alkaline acetates.

4. Sulphuric acid gives, with sugar, a black mass.

5. To detect *free* sulphuric acid, mix the fluid with a very little cane-sugar and evaporate to dryness at 212°F. (100°C.). If any is present, a black residue will remain; or with small traces a blackish-green residue. No other free acid decomposes cane-sugar in this way.

Cyanides and Acetates

Cyanides.—These give a blue color with a mixture of ferrous and ferric salts.

Some additional tests for other acids are:

A concentrated solution in hydrochloric acid will, when H_2S is passed in, give a precipitate of sulphur if it contains nitrates, nitrites, chlorates, sulphites, thiosulphates, arsenates, chromates, manganates or permanganates.

Acetates evolve a characteristic odor when present in large quantity in strong sulphuric-acid solution. They give a blood-red solution with ferric salts. If the solution be neutral the iron is precipitated on boiling.

SOME PROPERTIES OF RADIOACTIVE SUBSTANCES

The table below is based on tables in *Le Radium,* Jan., 1909, Jan., 1910 and Jan., 1911, and in *Zeit. für Angew. Chemie.* July 6, 1915. See also pages 234–237.

Substance	Properties
U	Sol. in excess of am. carb. Nitrate soluble in ether and acetone. Atomic weight, 238.2. Half-decay period, 6×10^9 years. Gives off α particles.
UX	Carried down by $BaSO_4$. Soluble in HCl. Less volatile than U. Volatile in electric arc. Insoluble in excess of am. carb. Soluble in water and ether. Half-decay period, 24.6 days. Gives off β and γ particles.
UY	Carried down by barium sulphate with moist ferric hydrate, and by animal charcoal. Half-decay period, 1.5 days.
Io	Soluble in excess of am. oxalate. Carried down by H_2O_2 in presence of U salts. Half-decay period, over 2×10^5 years (?). Gives off α particles.
Ra	Characteristic spectrum. Spontaneously luminous. Analogous to Ba. $RaCl_2$ and $RaBr_2$ are less soluble than $BaCl_2$ and $BaBr_2$. Atomic weight, 226.4. Half-decay period, 2000 years. α and β particles.
RaEm (Niton)	One of group of inert gases. Characteristic spectrum. Mol. wt. = 218. Half-decay period, 3.85 days.
RaA	Behaves as a solid. Deposited on cathode in an electric field. Volatile at 800–900°C. Soluble in strong acids. Half-decay period, 3 min.
RaB	Like RaA. Volatile at 600–700°C. Precipitated by $BaSO_4$. Half-decay period, 26.8 min.
RaC	Physically like RaA. Volatile at 800–1300°C. Chemically like RaB. Deposited on Cu and Ni. Perhaps a mixture of two products.
RaD	Volatile below 1000°C. Soluble in strong acids. Reactions of RaD and RaE_1 analogous to those of Pb. Sometimes known as radiolead.
RaE_1	Volatile at red heat. Soluble in cold acetic acid.
RaE_2	Not volatile at red heat. Reactions similar to Bi.
RaF (Polonium.)	Volatile toward 1000°C. Deposited from its solutions on Bi, Cu, Sb, Ag, Pt. Carried down by $PbCO_3$, and by $SnCl_2$ with Hg and Te. RaD, E_1, E_2, and F can be separated by electrolysis.
Ac	Produces helium. Precipitated by oxalic acid in acid solutions. Oxalate insoluble in HF; accompanies thorium and rare earths. Unknown period.
ad. Ac	Slightly volatile at high temps. Insoluble in NH_4OH. Separated from Ac by electrolysis, by fractional precipitation, by ammonia, and by animal charcoal. Half-decay period, 19.5 days.

AcX	Deposited by electrolysis in alkaline solution. Not precipitated by NH_4OH. Half-decay, 10.5 days.
AcEm	Behaves as inert gas. Gives off α particles only. Condenses at $-120°C$. Half-decay, 3.9 sec.
AcA	Volatile below 400°C. Soluble in NH_4OH and strong acids. Half-decay, 0.002 sec. α radiation.
AcB	Volatile below 700°C. Soluble in NH_4OH and strong acids. Deposited by electrolysis of active deposits on cathode in HCl. Half-decay, 36 min.
Th	Volatile in electric arc. Colorless salts not spontaneously phosphorescent. Salts ppd. by NH_4OH and oxalic acid. Atomic weight, 232.4.
Rad. Th	Carried down by hydrates, precipitated by NH_4OH.
ThX	Soluble in NH_4OH. Carried down by iron. Deposited by electrolysis in alkalis. 3.64 days.
ThEm	Inert gas. Condenses just above $-120°C$. Half-decay period, 54.5 sec.
ThA.	Volatile under 630°C. Soluble in strong acids.
ThB	Volatile below 730°C. Like ThA. Deposited on Ni. Separated from ThA by electrolysis.
ThC	Like ThB. Probably two products. α particles.

One gram of radium gives off 0.0328 cal. per sec., and produces 5.17×10^{-9} cc. of helium (0°, 76 cm. pressure) per gram per sec.

STANDARDS FOR WORK WITH THE BOMB CALORIMETER[1]

	Berthelot	Atwater	Fischer & Wrede	U. S. Bureau of Standards
Naphthalene.........	9692	9628	9640	9610
Benzoic acid..........	6322	6322	6333	6320
Cane sugar (sucrose)..	3961	....	3957	....

Heats of Formation

Heats of formation are expressed in calories, *i.e.*, the amount of heat necessary to raise 1 gram of water from 10°C. to 11°C. When it is said that the heat of formation of any compound is a certain number of units, it is meant that this number of calories is developed in the production of a mass in grams of the substance equal to its molecular weight, *i.e.*, when we say that

$$C + O_2 = CO_2 \ 97{,}200 \text{ cal.}$$

we mean that 12 grams of carbon and 32 of oxygen develop 97,200 cal.

The heat of formation and the heat of decomposition of any substance are the same; *i.e.*, in order to effect the decomposition of a substance an amount of heat must be supplied equal to the amount evolved in the formation.

The heat of combination of the elements, like many others of their properties, follows the periodic law, the relation being thus stated by W. G. MIXTER (*Am. Journ. Sci.*, June, 1914): The heat equivalents of the elements of a subgroup in the series

[1] From SOMERMEIER'S "Coal."

III to VIII are either linear functions of the atomic weights, or the heat of formation of the oxide of the middle member falls below the linear value by a constant amount for each atom of oxygen combined.

Heat of Formation of Silicates

Starting from	Gram-cal. per molecule	Gram-cal. per gram of silicate formed	Starting from	Gram-cal. per molecule	Gram-cal. per gram of silicate formed
FeO, SiO_2	10,600	80	Fe, Si, O_3	254,600	1,929
MnO, SiO_2	5,400	41	Mn, Si, O_3	276,300	2,109
BaO, SiO_2	14,700	69	Ba, Si, O_3	328,100	1,540
CaO, SiO_2	17,850	154	Ca, Si, O_3	329,350	2,839
$2CaO, SiO_2$	28,300	165	Ca_2, Si, O_4	471,300	2,740
$3CaO, SiO_2$	28,550	125	Ca_3, Si, O_5	603,050	2,645
SrO, SiO_2	17,900	110	Sr, Si, O_3	329,100	2,019
$Al_2O_3, 2SiO_2$	14,900	67	Al_2, Si_2, O_7	767,500	3,457
$3CaO, Al_2O_3, 2SiO_2$	33,500	86	Ca_3, Al_2, Si_2, O_{10}	1,195,550	3,065
$3H_2O, Al_2O_3, 2SiO_2$	43,800	170	H_2, Al_2, Si_2, O_9	927,420	3,595
Li_2O, SiO_2	65,100	720	Li_2, Si_2, O_3	347,100	3,856
Na_2O, SiO_2	45,200	370	Na_2, Si, O_3	326,100	2,673
CaO, Al_2O_3	450	3	Ca, Al_2, O_4	524,550	3,220
$2CaO, Al_2O_3$	3,300	15	Ca_2, Al_2, O_5	658,900	3,079
$3CaO, Al_2O_3$	2,950	11	Ca_3, Al_2, O_6	789,050	2,922
SiO_2 35.5, FeO, 39.7, MnO, 1.0, CaO 11.4, MgO 2.7, Al_2O_3 9.2, Cu 0.42, S 0.42 per cent.	......	133	......	......	......
$2FeO, SiO_2$	22,236	109	Fe_2, Si, O_4	333,636	1,637
FeO 70.80, SiO_2 29.20 per cent.					
FeO 57.58, CaO 12.00, SiO_2 30.42 per cent.	......	140	......	......	......
FeO 40.30, CaO 28.00, SiO_2 31.70 per cent.	......	193	......	......	......

Heats of Formation of Mixtures of SiO_2, CaO, and Anhydrous Kaolin

The kaolin used in these experiments was: SiO_2, 53.58 per cent., Al_2O_3, 43.40, Fe_2O_3, 1.25. The difference between the sum of the Al_2O_3 and CaO and 100% is the SiO_2.

Al_2O_3 per cent. / CaO per cent.	2	10	20	30
10	......	......	+ 19.2	+ 1.7
20	......	+ 42.8	+ 47.9	+49.9
30	+ 76.1	+ 69.7	+ 82.3	+73.0
40	+103.2	+109.0	+106.5	......
50	+150.6	+135.8	+137.8	......
60	+154.0	+180.4	......	......

[1] Revue de Metallurgie, 1913, p. 673.

Heat of Formation of Oxides

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Mg, O	24+16=40	143,400	148,800
Ba, O	137+16=153	133,400[1]	161,500
Ca, O	40+16=56	131,500	149,600
Sr, O	87+16=103	131,200	158,400
Al_2, O_3	54+48=102	392,600	....
Ti, O_2	48+32=80	218,500	....
Na_2, O	46+16=62	100,900	155,900
K_2, O	78+16=94	98,200	165,200
Si, O_2	28+32=60	180,000	180,000[6]
Mn, O	55+16=71	90,900	....
B_2, O_3	22+48=70	272,600	279,900
Zn, O	65+16=81	84,800[2]	82,680
Mn_3, O_4	165+64=229	328,000	....
P_2, O_5	62+80=142	365,300	405,000[6]
Sn, O	118+16=134	70,700	....
Sn, O_2	118+32=150	141,300	....
CO, O	28+16=44	[6]68,040	73,940
H_2, O	2+16=18	70,400 solid	....
	2+16=18	69,000 liquid	
	2+16=18	58,060 gas	
H_2 O_2 [3]	2+32=34	....	47,300[3]
Fe_3, O_4	168+64=232	270,800	....
Cd, O	112+16=128	66,300	....
Fe, O	56+16=72	65,700	....
Fe_2, O_3	112+48=160	195,600	....
Co, O	59+16=75	64,100	....
Mn, O_2	55+32=87	125,300	....
Ni, O	58.5+16=74.5	61,500	....
Sb_2, O_3	240+48=288	166,900	....
As_2, O_3	150+48=198	156,400	148,900
Pb, O	207+16=223	50,800	....
C, O_2	12+32=44	97,200 gas	103,100
Bi_2, O_3	416+48=464	139,200[4]	....
Sb_2, O_5	240+80=320	231,200	....
As_2, O_5	150+80=230	219,400	225,400
Cu_2, O	127.2+16=143.2	43,800	....
Tl_2, O	408+16=424	42,800	39,700
Cu, O	63.6+16=79.6	37,700	....
Ba, O_2	137+32=169	145,500	....
S, O_2	32+32=64	69,260 gas	77,600
Pb, O_2	207+32=239	63,400	....
S, O_3	32+48=80	91,900[5]	141,000
Tl_2, O_3	408+48=456	87,600	....
C, O	12+16=28	29,160 gas	....
Hg_2, O	400+16=416	22,200	....
Hg, O	200+16=216	21,500	....
Te, O_2	125.5+32=157.5	....	78,300
Pd, O	106+16=122	21,000	....
Pt, O	195+16=211	17,000	....
Ag_2, O	216+16=232	7,000	....
Au_2, O_3	394+48=442	−11,500	....
N_2, O	28+16=44	−19,000[6]	....
N, O	14+16=30	−21,600[6]	....
N_2, O_3	28+48=76	−21,400[6]	....
N, O_2 (at 22°)	14+32=46	−1,700[6]	....
N, O_2 (at 150°)	14+28=42	−7,600[6]	....
N_2O_5	28+70=98	....	3,600[6]
Cs_2O	266+16=282	100,000	....
Li_2O	14+16=30	140,000	....
Rb_2O	171+16=187	94,900	....
W, O_3	184+48=232	243,000	....
V_2, O_5	102+80=182	441,000	....
Cr_2, O_3	104+48=152	266,000[7]	....

[1] Thomsen, 126,000. [2] 42,740 at 1125°C. [3] "Annuaire des Bureau des Longitudes," 1914. [4] Kaye and Laby, 20,000. [5] Kaye and Laby, 103,000. [6] Thomsen, "Thermochemistry."

[7] This is the heat evolved by a stable amorphous oxide. There is an unstable form evolving only 243,000 cal.

Heat of Formation of Hydroxides

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Li, O, H..........	7+16+1=24	112,300	118,110
Mg, O_2, H_2........	24+32+2=58	217,800	....
Sr, O_2, H_2.........	87+32+2=121	217,300	227,400
Ca, O_2, H_2.........	40+32+2=74	215,600[1]	219,500
K, O, H..........	39+16+1=56	104,600	117,100
Na, O, H..........	23+16+1=40	102,700	112,500
N, O, H_5..........	18+16+1=35	88,800	90,000
Al, O_3, H_3.........	27+48+3=78	301,300	....
H, O, H..........	1+16+1=18	70,400 solid 69,000 liquid 58,060 gas	....
Tl, O, H..........	204+16+1=221	57,400	54,300
Bi, O_3, H_3.........	208+48+3=259	171,700	....
Zn, O_2, H_2.........	65+32+2=99	83,500	....
Te, O_2, H_2.........	127+32+2=161	78,300	....
Te, O_3, H_3.........	127+48+3=178	99,500	....
Se, O_2, H_2.........	79+32+2=113	52,400	51,500
Se, O_3, H_3.........	79+48+3=130	79,300	....
Tl, O_3, H_3.........	204+48+3=255	43,800	....
Ba, O_2, H_2.........	137+32+2=171	217,000[2]	....
Cd, O_2, H_2.........	112+32+2=146	66,000[2]	....
Cs, O, H..........	133+16+1=150	101,300	....
Rb, O, H..........	85.5+16+1=102.5	102,000	....

[1] Kaye and Laby, 229,000.
[2] Thomsen, "Thermochemistry."

Heat of Formation of Cyanides

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Ca, C_2, N_2......	40+ 24+ 28= 92	....	41,650
K, C, N........	39+ 12+ 14= 65	33,450	30,250
Na, C, N.......	23+ 12+ 14= 49	25,950	25,450
K, Ag, C_2, N_2...	39+108+ 24+ 28=199	13,700	5,350
Fe_7, C_{18}, N_{18}....	392+216+252=860	−256,700	....
Zn, C_2, N_2......	65+ 24+ 28=117	− 24,550	....
Cd, C_2, N_2......	112+ 24+ 28=164	− 31,850	....
Cu, C, N.......	63.6+ 12+ 14=89.6	− 20,375	....
Pd, C_2, N_2......	106+ 24+ 28=158	− 49,250	....
H, C, N........	1+ 12+ 14= 27	− 27,150 (gas)	−21,050
Hg, C_2, N_2......	200+ 24+ 28=252	− 59,150	....

Heat of Formation of Cyanates

Formula	Molecular weights	Molecular heat of formation	In dilute solution
K, C, N, O.......	39+12+14+16= 81	105,850	100,650
Na, C, N, O......	23+12+14+16= 65	105,050	100,250
Ag, C, N, O......	108+12+14+16=150	26,450	....

Heat of Formation of Ferrocyanides

Formula	Molecular weights	Molecular heat of formation	In dilute solution
K_4, Fe, C_6, N_6	156+56+72+84=368	157,300	145,300
H_4, Fe, C_6, N_6	4+56+72+84=216	−102,000	−101,500
K_3, Fe, C_6, N_6	117+56+72+84=329	129,600	100,800
H_3, Fe, C_6, N_6	3+56+72+84=215	....	−127,400

Heat of Formation of Selenides

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Li_2, Se	14+79=93	83,000	93,700
K_2, Se	78+79=157	79,600	87,900
Ba, Se	137+79=216	69,900	....
Sr, Se	87+79=166	67,600	....
Ca, Se	40+79=119	58,000	....
Na_2, Se	46+79=125	60,900	78,600
Zn, Se	65+79=144	30,300	....
Cd, Se	112+79=191	23,700	....
Mn, Se	55+79=134	22,400	....
N, H_5, Se	14+5+79=98	17,800	12,800
Cu, Se	63.6+79=142.6	17,300	....
Pb, Se	207+79=286	17,000	....
Fe, Se	56+79=135	15,200	....
Ni, Se	58.5+79=137.5	14,700	....
Co, Se	59+79=138	13,900	....
Tl_2, Se	408+79=487	13,400	....
Cu_2, Se	127.2+79=206.2	8,000	....
Hg, Se	200+79=279	6,300	....
Ag_2, Se	216+79=295	2,000	....
H_2, Se	2+79=81	−25,100 (gas)	−15,800
N, Se	14+79=93	−42,300	....

Heat of Formation of Tellurides

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Zn, Te	65+126=191	31,000	....
Cd, Te	112+126=238	16,600	....
Co, Te	59+126=185	13,000	....
Fe, Te	56+126=182	12,000	....
Ni, Te	58.5+126=184.5	11,600	....
Tl_2, Te	408+126=534	10,600	....
Cu_2, Te	127.2+126=253.2	8,200	....
Pb, Te	207+126=333	6,200	....
H_2, Te	2+126=128	−34,900 (gas)	....

Heat of Formation of Sulphides

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Li_2, S	14+32=46	....	115,400
K_2, S	78+32=110	103,500	113,500
Ba, S	137+32=169	102,900	109,800
Sr, S	87+32=119	99,300	106,700
Ca, S	40+32=72	94,300	100,600
Na_2, S	46+32=78	89,300	104,300
Mg, S	24+32=56	79,400	....
K, S_2	39+64=103	59,300	59,700
Na, S_2	23+64=87	49,500	54,400
Mn, S	55+32=87	45,600	....
Zn, S	65+32=97	43,000	....
Al_2, S_3	54+96=150	126,400	....
N, H_5, S	14+5+32=51	40,000	36,700
Cd, S	112+32=144	34,400	....
B_2, S_3	22+96=118	75,800	....
Fe, S	56+32=88	24,000	....
Co, S	59+32=91	21,900	....
Tl_2, S	204+32=236	21,600	....
Cu_2, S	127.2+32=159.2	20,300	....
Pb, S	207+32=239	20,200	....
Si, S_2	28+64=92	40,000	....
Ni, S	58.5+32=90.5	19,500	....
Sb_2, S_3	240+96=336	34,400	....
Hg, S	200+32=232	10,600	....
Cu, S	63.6+32=95.6	10,100	....
H_2, S	2+32=34	4,800 gas[1]	9,500
Ag_2, S	216+32=248	3,000	....
C, S_2	12+64=76	{ −25,400 gas −19,000 liquid	....
I, S	127+32=159	9,000	....

[1] Molecular heat of combustion of H_2S = 122,500 cal., and heat of combustion of 1 cu. meter H_2S = 5513 cal.

Heat of Formation of Nitrides

Formula	Molecular weights	Molecular heat of formation	In dilute solution
C_2, N_2	24+28=52	−73,900 gas	−68,300
H_3, N	3+14=17	{ 12,200 gas[1] 16,600 liquid	21,000
Ba_3, N_2	411+28=439	149,400	....
Li_3, N	21+14=35	49,500	....
K, H_2, N	39+3+14=56	30,700	....
Ca_3, N_2	120+28=148	111,200	....

[1] F. Haber gives 10,975. *Chem. Tr. Journ.*, Aug. 14, 1915.

Heat of Formation of Metallic Hydrides

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Sr, H_2	87+2=89	38,400	....
Ba, H_2	137+2=139	37,500	....
Pt_{10}, H	1950+1=1951	14,200	....
Pd_{15}, H	1590+1=1591	4,600	....
Si, H_4	28+4=32	−6,700[1] gas	....

[1] Kaye and Laby, 25,000.

Heat of Formation of Phosphides

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Mn_3, P_2	165+62=227	70,900	...
H_3, P	3+31=34	4,900	...
Fe, P	56+39=95	nearly 0	...

Arsenides, Antimonides, Borates

Formula	Molecular weights	Molecular heat of formation	In dilute solution
H_3, As	3+ 75=78	−44,200 gas	−36,700
H_3, Sb	3+120=123	−86,800 gas	...
Na_2, B_2, O_7	46+44+112=202	748,100	758,300

Heat of Formation of Fluorides

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Sr, F_2	87+38=125	224,020	...
Ba, F_2	137+38=175	224,000	221,500
Li, F	7+19=26	...	116,880
K, F	39+19=58	110,000	113,600
Ca, F_2	40+38=78	216,450	...
Mg, F_2	24+38=62	209,500	...
Na, F	23+19=42	109,720	109,120
N, H_4, F	14+4+19=37	101,250	99,750
Al, F_3	27+57=84	...	275,220
B, F_3	11+57=68	...	219,345
Mn, F_2	55+38=93	...	153,310
Zn, F_2	65+38=103	...	138,220
Si, F_4	28+76=104	275,920 gas	...
Fe, F_2	56+38=94	...	125,220
Cd, F_2	112+38=150	...	121,720
Co, F_2	59+38=97	...	120,340
Ni, F_2	58.5+38=96.5	...	118,980
Fe, F_3	56+57=113	...	164,940
Tl, F	204+19=223	...	54,405
Pb, F_2	207+38=245	101,600	...
H, F	1+19=20	38,500 gas	50,300[1]
Sb, F_3	120+57=177	...	136,680
Cu, F_2	63.6+38=101.6	...	88,160
Ag, F	108+19=127	22,070	25,470

[1] Other authorities, 69,000.

Heat of Formation of Silicides

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Mn_7, Si_2	385+56=441	47,400	...
H_4, Si	4+28=32	−6,700 gas	...

Heat of Formation of Carbides

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Al_4, C_3	108+36=144	232,000	....
Mn, C_2	55+24=79	114,400	....
Mn, C_3	55+36=91	9,900	....
Fe_3, C	168+12=180	8,460	....
Ca, C_2	40+24=64	−6,250	−131,500
Na, C	23+12=35	−4,400	....
Li, C	7+12=19	−5,750	....
N_2, C_2	28+24=52	−73,000 gas	−67,100
Ag, C	108+12=120	−43,575	....
Mn_3, C	165+12=177	10,400	....

Heat of Formation of Bromides

Formula	Molecular weights	Molecular heat of formation	In dilute solution
		Liquid bromine	
Na,Br	23+ 80=103	79,450	....
K,Br	46+ 80=126	99,050	....
Al,Br_3	27+240=267	120,600	207,500
Zn,Br_2	65+160=225	78,200	93,200
Cd,Br_2	112+160=272	76,200	77,200
Pb,Br_2	207+160=367	69,000	59,000
Sn, Br_2	118+160=278	63,000	....
Cu, Br_2	63+ 80=143	26,000	....
Sn, Br_4	118+320=438	101,400 (solid) 98,400 (liquid)	118,000
Hg, Br	200+ 80=280	24,500	....
Ag, Br (cryst.)	108+ 80=188	23,700	....
Sb, Br_3	120+240=360	64,900	....
Cu, Br_2	63+160=223	34,800	53,000
Pt, Br_4	195+320=515	42,400	52,200
Au, Br_3	197+240=437	12,100[1]	8,400
Au, Br_2	197+160=357	1,000	....
H, Br	1+ 80=81	8,400	28,600

[1] 8800 Berthelot.

Heat of Formation of Iodides

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Zn, I_2	65+254=319	49,200	60,600
Cd, I_2	112+254=366	45,000	44,000
Pb, I_2	207+254=461	42,000	....
Cu, I_2	63.5+254=317.5	16,500	....
Hg, I_2	200+254=454	14,200	....
Ag, I (cryst.)	108+127=235	14,300	....
Hg, I_2 (red)	200+254=454	24,300	....
Sb, I_3	120+381=501	29,200	....
Au, I	197+127=324	−55,000	....
H, I	1+127=128	− 6,400	13,200
K, I	46+127=173	87,500	....
Na, I	23+127=150	76,500	....

Heat of Formation of Carbonates

ormula	Molecular weights	Molecular heat of formation	In dilute solution
O_3.........	137+12+48=197	286,300	....
O_3.........	78+12+48=138	282,100	288,600
O_3.........	87+12+48=147	281,400	....
O_3.........	40+12+48=100	273,850	....
, O_3........	46+12+48=106	273,700	279,300
O_3........	24+12+48= 84	269,900	....
O_3........	55+12+48=115	210,300	....
O_3.........	65+12+48=125	197,500	....
O_3.........	56+12+48=116	187,800	....
O_3.........	112+12+48=172	183,200	....
O_3.........	207+12+48=267	170,000	....
O_3.........	63.6+12+48=123.6	146,100	....
O_3........	216+12+48=276	123,800	....
I, CO_3.....	14+4+1+12+48=79	205,300	199,000

Heat of Formation of Bicarbonates.

ormula	Molecular weights	Molecular heat of formation	In dilute solution
C, O_3.......	39+1+12+48=100	233,300	228,000
C, O_3......	23+1+12+48= 84	227,000	222,700

Heat of Formation of Sulphates

rmula	Molecular weights	Molecular heat of formation	In dilute solution
O_4........	78+32+ 64=174	344,300	337,700
O_4........	137+32+ 64=233	339,400	....
O_4........	14+32+ 64=110	333,500	339,600
O_4.........	87+32+ 64=183	330,200	....
O_4.......	46+32+ 64=142	328,100	328,500
O_4........	40+32+ 64=136	317,400	321,800
O_4........	24+32+ 64=120	300,900	321,100
O_{12}.......	54+96+192=342	....	879,700
S, O_4.....	28+8+32+ 64=132	283,500	281,100
O_4.......	55+32+ 64=151	249,400	263,200
O_4........	65+32+ 64=161	229,600	248,000
O_4........	56+32+ 64=152	....	234,900[1]
O_4........	59+32+ 64=155	....	228,900
O_4........	58.5+32+ 64=154.5	....	228,700
O_{12}......	112+96+192=400	....	650,500
O_4........	408+32+ 64=504	221,800	213,500
O_4........	112+32+ 64=208	219,900	231,600
O_4........	207+32+ 64=303	215,700	....
O_4........	2+32+ 64= 98	192,200	210,200
O_4........	63.6+32+ 64=159.6	181,700	197,500
O_4.......	400+32+ 64=496	175,000	....
O_4.......	216+32+ 64=312	167,100	162,600
O_4........	200+32+ 64=296	165,100	....
$O_4 \cdot 7H_2O$...	59+32+64+126=281	234,000	....
S, O_4....	28+ 8+32+ 64=132	283,500	281,100
O_4.......	171+32+ 64=267	344,700	....
O_4.........	266+32+ 64=362	349,700	....

000 for $FeSO_4 \cdot 7H_2O$.

Heat of Formation of Chlorides

Formula	Molecular weights	Molecular heat of formation	In dilute solution
K, Cl	39 + 35.5 = 74.5	105,700	101,200
Ba, Cl_2	137 + 71 = 208	197,100	198,300
Be, Cl_2	9 + 71 = 80	155,000	199,500
Na, Cl	23 + 35.5 = 58.5	97,900	96,600
Li, Cl	7 + 35.5 = 42.5	93,900	102,300
Sr, Cl_2	87 + 71 = 158	184,700	195,850
Ca, Cl_2	40 + 71 = 111	169,900	187,400
N, H_4, Cl	14 + 4 + 35.5 = 53.5	76,800	72,800
Mg, Cl_2	24 + 71 = 95	151,200	187,100
S, Cl_2	28 + 142 = 170	128,800 gas	....
Al, Cl_3	27 + 106.5 = 133.5	161,800	238,100
Mn, Cl_2	55 + 71 = 126	112,000	128,000
Zn, Cl_2	65 + 71 = 136	97,400	113,000
Tl, Cl	204 + 35.5 = 239.5	48,600	38,400
Cd, Cl_2	112 + 71 = 183	93,700	96,400
Pb, Cl_2	207 + 71 = 278	83,900	77,900
Fe, Cl_2	56 + 71 = 127	82,200	100,100
Sn, Cl_2	118 + 71 = 189	80,900	....
Co, Cl_2	59 + 71 = 130	76,700	95,000
Ni, Cl_2	58.5 + 71 = 129.5	74,700	93,900
Cu, Cl	63.5 + 35.5 = 99	35,400	....
Sn, Cl_4	118 + 142 = 260	129,800 liquid	....
Fe, Cl_3	56 + 106.5 = 162.5	96,150	127,850
Hg, Cl	200 + 35.5 = 235.5	31,320	....
Sb, Cl_3	120 + 106.5 = 226.5	91,400	....
Bi, Cl_3	208 + 106.5 = 314.5	90,800	....
B, Cl_3	11 + 106.5 = 117.5	89,100 gas	93,400
Ag, Cl	108 + 35.5 = 143.5	29,000	....
Hg, Cl_2	200 + 71 = 271	53,300	50,300
Cu, Cl_2	63.6 + 71 = 134.6	51,400	62,500
As, Cl_3	75 + 106.5 = 181.5	71,500	....
H, Cl	1 + 35.5 = 36.5	22,000	39,400
Sb, Cl_5	120 + 177.5 = 297.5	104,500 liquid	....
Pd, Cl_2	106 + 71 = 177	40,500	....
Pt, Cl_4	195 + 142 = 337	60,200	79,800
Au, Cl_3	197 + 106.5 = 303.5	22,800	27,200
Au, Cl	197 + 35.5 = 232.5	5,800	....
P, Cl_3	31 + 106.5 = 137.5	69,700	....
Rb, Cl	85.5 + 35.4 = 120.9	105,900	....
Cs, Cl	133 + 35.4 = 168.4	109,900	....
Zr, O_2	91 + 32 = 123	177,500	....
Ce, O_2	140 + 32 = 172	224,600	....

Heat of Formation of Phosphates and Miscellaneous Acids

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Ca_3, P_2, O_8	120 + 62 + 128 = 310	919,200	....
Mg_3, P_2, O_8	72 + 62 + 128 = 262	910,600	....
Na_3, P, O_4	69 + 31 + 64 = 164	452,400	....
H_3, P, O_4[1]	3 + 31 + 64 = 98	....	302,000
H, Br, O_3[1]	1 + 80 + 48 = 129	....	12,500
H, Cl, O_3[1]	1 + 35.5 + 48 = 84.5	....	22,000
H, Cl, O_4[1]	1 + 35.5 + 64 = 100.5	....	39,100
H, I, O_3[1]	1 + 127 + 48 = 176	....	57,700
H_3, P, O_3[1]	3 + 31 + 48 = 82	....	228,800

[1] These results from "Annuaire du Bureau des Longitudes," 1914

Heat of Formation of Bi-sulphates

Formula	Molecular weights	Molecular heat of formation	In dilute solution
K, H, S, O_4	39+1+32+64=136	276,100	272,900
Na, H, S, O_4	23+1+32+64=120	269,100	268,300
N, H_5, S, O_4	14+5+32+64=115	244,600	245,100
H, H, S, O_4	1+1+32+64= 98	192,200	210,200

Heat of Formation of Sulphites

Formula	Molecular weights	Molecular heat of formation	In dilute solution
S, O_3, K_2	32+48+78=158	....	272,600
S, O_3, Na_2	32+48+46=126	....	261,000

Heat of Formation of Nitrates

Formula	Molecular weights	Molecular heat of formation	In dilute solution
K, N, O_3	39+14+ 48=101	119,000	110,700
Na, N, O_3	23+14+ 48= 85	110,700	106,000
Zn, N_2, O_6	65+28+ 96=187	....	131,700
Pb, N_2, O_6	207+28+ 96=331	105,400	98,200
Cu, N_2, O_6	63.5+28+ 96=187.5	....	81,300
H, N, O_3	1+14+ 48= 63	34,400 gas	48,800
Ag, N, O_3	108+14+ 48=170	28,700	23,000
Ca, N_2, O_6[1]	40+28+ 96=164	202,000	....
$Co, N_2, O_6 \cdot 6H_2O$[1]	59+28+96+108=283	....	119,000
$LiNO_3$[1]	7+14+ 48= 69	112,000	....
N, H_4, N, O_3[1]	14+ 4+14+ 48= 80	88,600	82,400

Heat of Formation of Aluminates

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Ca, Al_2, O_4	40+54+64=158	524,550	....
Ca_2, Al_2, O_5	80+54+80=214	658,900	....
Ca_3, Al_2, O_6	120+54+96=270	789,050	....

Heat of Formation of Amalgams

Formula	Molecular weights	Molecular heat of formation	In dilute solution
Hg_{12}, K	2,400+ 39=2,439	34,600	25,600
Hg_4, K	800+ 39=839	29,700	25,600
Hg_6, Na	1,200+ 23=1,223	21,900	19,000
Hg_x, Au	x+197=197+x	....	2,580
Hg_x, Ag	x+108=108+x	....	2,470

Heat of Formation of Alloys

Formula	Molecular weights	Molecular heat of formation	In dilut solutio
Cu, Zn_2	63.6+130=193.6	10,143	....
Cu, Zn	63.6+ 65=128.6	5,783	....
Cu_3, Al	190.8+ 27=217.8	26,910	....
Cu_2, Al	127.2+ 27=154.2	21,278	....
Cu_3, Al_2	190.8+ 54=244.8	17,395	....
Cu, Al	63.6+ 27=90.6	1,887	....
Cu_2, Al_3	127.2+ 81=208.2	10,196	....
Cu, Al_2	63.6+ 54=117.6	−6,738	....

Dehydration of Metallic Sulphates

	Temperature of beginning dehydration, deg. C.	Product formed	Remarks
$FeSO_4 + 7H_2O$	21	$FeSO_4 + 4H_2O$	Slight apple g
$FeSO_4 + 4H_2O$	80	$FeSO_4 + H_2O$	White.
$FeSO_4 + H_2O$	406	$Fe_2O_3 + 2SO_3$	Yellowish br
$Al_2(SO_4)_3 + 16H_2O$	51	$Al_2(SO_4)_3 + 13H_2O$	White.
$Al_2(SO_4)_3 + 13H_2O$	82	$Al_2(SO_4)_3 + 10H_2O$	White.
$Al_2(SO_4)_3 + 10H_2O$	97	$Al_2(SO_4)_3 + 7H_2O$	White.
$Al_2(SO_4)_3 + 7H_2O$	109	$Al_2(SO_4)_3 + 4H_2O$	White.
$Al_2(SO_4)_3 + 4H_2O$	180	$Al_2(SO_4)_3 + H_2O$	White.
$Al_2(SO_4)_3 + H_2O$	316	$Al_2(SO_4)_3$	White.
$CuSO_4 + 5H_2O$	27	$CuSO_4 + 3H_2O$	Sky blue.
$CuSO_4 + 3H_2O$	93	$CuSO_4 + H_2O$	Pale blue.
$CuSO_4 + H_2O$	155	$CuSO_4$	White.
$MnSO_4 + 5H_2O$	25	$MnSO_4 + 2H_2O$	Pale peach blossom.
$MnSO_4 + 2H_2O$	60	$MnSO_4 + H_2O$	Paler than ceding.
$MnSO_4 + H_2O$	152	$MnSO_4$	Paler than ceding.
$ZnSO_4 + 7H_2O$	25	$ZnSO_4 + 6H_2O$	White.
$ZnSO_4 + 6H_2O$	28	$ZnSO_4 + 2H_2O$	White, granu
$ZnSO_4 + 2H_2O$	115	$ZnSO_4 + H_2O$	White.
$ZnSO_4 + H_2O$	225	$ZnSO_4$	White.
$NiSO_4 + 7H_2O$	40	$NiSO_4 + 4H_2O$	Green.
$NiSO_3 + 4H_2O$	106	$NiSO_4 + H_2O$	Yellow.
$NiSO_4 + H_2O$	279	$NiSO_4$	Orange colo
$CoSO_4 + 7H_2O$	19	$CoSO_4 + 4H_2O$	Rose.
$CoSO_4 + 4H_2O$	58	$CoSO_4 + H_2O$	Lilac.
$CoSO_4 + H_2O$	276	$CoSO_4$	Lilac.
$CdSO_4 + \frac{8}{3}H_2O$	30	$CdSO_4 + 2H_2O$	White.
$CdSO_4 + 2H_2O$	41	$CdSO_4 + H_2O$	White.
$CdSO_4 + H_2O$	170	$CdSO_4$	White.
$MgSO_4 + 7H_2O$	19	$MgSO_4 + 6H_2O$	White.
$MgSO_4 + 6H_2O$	38	$MgSO_4 + 2H_2O$	White.
$MgSO_4 + 2H_2O$	112	$MgSO_4 + H_2O$	White.
$MgSO_4 + H_2O$	203	$MgSO_4$	White.
$CaSO_4 + 2H_2O$	38	$CaSO_4 + H_2O$	White.
$2CaSO_4 + 2H_2O$	80	$2CaSO_4 + H_2O$	White.
$2CaSO_4 + H_2O$	149	$2CaSO_4$	White.

HEAT OF FORMATION OF HYDROCARBONS
(All formed in state of gas, unless otherwise specified)

Name	Formula	Molecular weights	Molecular heat of formation	Molecular heat of complete combustion	Heat of combustion 1 m.³ (cal.)	Heat of combustion 1 ft.³ B.t.u.
Methane (marsh gas)	(C, H_4)	12+ 4= 16	22,250	191,070	8,598	966
Ethane (ethylene hydride)	(C_2, H_6)	24+ 6= 30	26,650	341,930	15,387	1,728
Propane (propylene hydride)	(C_3, H_8)	36+ 8= 44	33,850	489,900	22,050	2,477
Ethylene (olefiant gas)	(C_2,H_4)	24+ 4= 28	−11,250	321,770	14,480	1,627
Propylene	(C_3, H_6)	36+ 6= 42	− 6,050	471,830	21,232	2,385
Toluene	(C_7, H_8)	84+ 8= 92	5,650 (liquid)	906,990	....	....
Benzene	(C_6, H_6)	72+ 6= 78	− 750 (liquid)	758,130	....	....
			− 7,950 (gas)	765,330	34,440	3,869
Turpentine	(C_{10}, H_{16})	120+16=136	7,550 (liquid)	1,428,930	....	....
			− 1,850 (gas)	1,438,330	64,725	7,271
Naphthaline	(C_{10}, H_8)	120+ 8=128	−19,450 (solid)	1,223,690	....	....
			−24,050 (liquid)	1,228,290	55,273	6,209
Anthracene	(C_{14}, H_{10})	168+10=178	−39,050 (solid)	1,690,150	....	....
Acetylene	(C_2, H_2)	24+ 2= 26	−54,750	365,270	16,437	1,846
Methyl-alcohol (wood spirit)	(C, H_4, O)	12+4+16= 32	65,050 (liquid)	148,270	....	....
			56,650 (gas)	156,670	7,050	799
Ethyl-alcohol (alcohol)	(C_2, H_6, O)	24+6+16= 46	73,250 (liquid)	295,330	....	....
			63,150 (gas)	305,430	13,744	1,544
Acetone	(C_3, H_6, O)	36+6+16= 58	69,650 (liquid)	396,130	....	....
			62,150 (gas)	403,630	18,163	2,040

HEAT OF SOLUTION

Salt dissolved	Calories
$CuSO_4.5H_2O$	−2,750
$CdSO_4.\frac{8}{3}H_2O$	2,660
$ZnSO_4.7H_2O$	−4,260
$FeSO_4.7H_2O$	− 400
$ZnCl_2$ in water	15,630
$ZnSO_4$ in water	18,500

DESULPHATIZATION OF ANHYDROUS METALLIC SULPHAT

Metallic sulphates	Temperature of beginning of decomposition, deg. C.	Temperature of energetic decomposition, deg. C.	Products of decomposition	Remark
$Fe_2(SO_4)_3$	167	480	$Fe_2O_3.2SO_3$	Yellow brow
$Fe_2O_3.2SO_3$	492	560	Fe_2O_3	Red.
$Bi_2(SO_4)_3$	570	639	$5Bi_2O_3{\cdot}4(SO_3)_3$	White.
$Al_2(SO_4)_3$	590	639	Al_2O_3	White.
$PbSO_4$	637	705	$6PbO{\cdot}5SO_3$	White.
$CuSO_4$	653	670	$2CuO{\cdot}SO_3$	Orange color.
$MnSO_4$	699	790	Mn_3O_4	Dark red to b
$ZnSO_4$	702	720	$3ZnO{\cdot}2SO_3$	White, cold a
$2CuO{\cdot}SO_3$	702	736	CuO	Black.
$NiSO_4$	702	764	NiO	Brownish gre
$CoSO_4$	720	770	CoO	Brown to bla
$3ZnO{\cdot}2SO_3$	755	767	ZnO	Hot yellow, white.
$CdSO_4$	827	846	$5CdO{\cdot}SO_3$	White.
$5Bi_2O_3{\cdot}4(SO_3)_3$	870	890	Bi_2O_3(?)	Yellow.
$5CdO{\cdot}SO_3$	878	890	CdO	Black.
$MgSO_4$	890	972	MgO	White.
Ag_2SO_4	917	925	Ag	Silver white.
$6PbO{\cdot}5SO_3$	952	962	$2PbO{\cdot}SO_3$(?)	White to yell
$CaSO_4$	1200	....	CaO	White.
$BaSO_4$	1510	....	BaO	White.

DISSOCIATION TENSIONS OF SULPHATES AT VARIOUS TEM TURES. EXPRESSED IN MILLIMETERS OF MERCUR

Temp., deg. C.	$Fe_2(SO_4)_3$	$CuSO_4$	$Al_2(SO_4)_3$	$2CuO{\cdot}SO_3$	Z
550	9.8	25.5	9.8	....	....
600	22.8	28.7	16.0	27.6	....
650	58.0	37.7	25.8	33.0	....
675	94.0	50.5	34.0	....	
700	219.0	71.0	50.0	36.0	
725	....	148.0	82.0	39.0	....
750	....	....	....	46.0	
775	....	....	....	....	1
800	....	....	....	85.0	2

[1] Hofman, "General Metallurgy." For additional data on decomposit pp. 291, 495 and 496.

Reduction Temperatures of Metallic Oxides

Various metallic oxides were submitted to the action of hydrogen, carbon monoxide, ammonia and methane, at various temperatures for a period of 6 hours, and the investigators report in the *Journ. Soc. Chem. Ind.*, July 30, 1910, the lowest temperatures at which the oxides begin to lose oxygen. The accompanying tabulation shows the results obtained.

TEMPERATURES AT WHICH OXIDES OF THE METALS GIVE UP OXYGEN

Oxide	Carbon monoxide, deg. C.	Hydrogen, deg. C.	Ammonia, deg. C.	Methane, deg. C.
Au_2O_3	0 and below	0 and below	....	....
Ag_2O	0	0	....	....
Hg_2O	0	80	67	220
HgO (yellow)	0 and below	50	....	....
HgO (red)	90	115	157	200–210
Pb_2O	....	....	202	202
PbO_2	110	150	198	45
Pb_3O_4	150	170	Above 300	158
PbO	160	190	299	210
CuO	75	125	225	280
Cu_2O	....	....	208	230
CoO	140	....	....	....
ZnO	170	....	233	152–159
As_2O_3	60	....	....	....

Reduction Temperatures of Some Refractory Oxides[1]

Oxide and carbon	Reduction temperature	Remarks
BeO	2400°	Forms carbide.
MgO	.....	Oxide dissociates before reduction.
CaO	1540°	Carbide dissociates above 800°.
Al_2O_3	1800°	Forms carbide.
B_2O_3	2400°	Carbide sublimes.
MnO	1100°	Carbide dissociates at 1550°.
UO_2	1600°	Forms carbide.

Decomposition of Carbonates[2]

$ZnCO_3 = ZnO + CO_2$ .... 300°C.
$MgCO_3 = MgO + CO_2$ .... 650°C.
$FeCO_3 = FeO + CO_2$ .... 800°C.
$CaCO_3 = CaO + CO_2$ .... 812°C.

Decomposition of Sulphides[2]

Pyrite — $FeS_2 = FeS + S$ .... 565°C
Chalcopyrite .... 720°C.

[1] *Zeit. für angew. Chemie.*, p. 118, Vol. XXVIII, 1915.
[2] See pp. 495 and 496 for additional data.

Molecular Heat of Dilution[1]

The heat set free or absorbed on diluting a gram molecule of liquid with water is the molecular heat of dilution, thus on diluting HCl to (HCl, 300 H_2O) 17,300 cal. per 36.5 grams of HCl are set free; diluting $2NaCl$, nH_2O ($n = 20$) to ($2NaCl$, 100 H_2O) absorbs 1060 cal. per 2 × 58.65 grams of NaCl.

HCl $n = 0\ H_2O$		HNO_3 $n = 0\ H_2O$		H_2SO_4 $n = 0\ H_2O$		$NaOH$ $n = 3\ H_2O$		NH_3[2] n	
1	5,370	1	3,280	1	6,380	5	2,130	1	1,260
2	11,360	5	6,600	5	13,100	7	2,900	3	385
5	14,960	10	7,320	49	16,700	9	3,100	5.8	210
50	17,100	20	7,460	199	17,100	25	3,260	9.5	20
300	17,300	320	7,490	1,600	17,900	200	2,940	110	......

$2NaCl$ $n = 20\ H_2O$		$2NaNO_3$ $n = 12\ H_2O$		Na_2SO_4 $n = 50\ H_2O$		$ZnCl_2$ $n = 5\ H_2O$		$Zn(NO_3)_2$ $n = 10$	
100	-1,060	50	-2,260	100	- 665	10	1,850	15	910
200	-1,310	100	-3,290	200	-1,130	20	3,150	20	1,150
400	-1,410	200	-3,860	400	-1,380	50	5,320	50	1,200
....	....	400	-4,190	800	-1,480	100	6,810	100	1,100
....	....	....	....	....	....	400	8,020	200	1,070

[1] From KAYE and LABY, "Physical and Chemical Constants."
[2] Heat developed on diluting $NH_3 \cdot nH_2O$ to $NH_3 \cdot 200H_2O$ (BERTHELOT).

Thermochemical Constants Per Chemical Equivalent with Corresponding Voltages

In the table of thermo-chemical constants per chemical equivalents (by J. W. Richards, *Journ. Franklin Inst.*, 1906) the column headed "per chemical equivalents" gives the additional energy in case of the plus figures, or the smaller amount, in case of the negative, required to set free a chemical equivalent (molecular weight divided by valence) of the given substance as compared with the energy required to decompose the corresponding hydrogen compound.

In the formation of $CuCl_2$ the data in the table are − 7900 Cu, + 39,400 Cl_2 = 31,500 gram-cal. required for the decomposition of one chemical equivalent of $CuCl_2$, the corresponding drop in voltage is − 0.34 Cu, + 1.71 Cl_2 = 1.37 volts for the decomposition voltage of $CuCl_2$. The order in which the elements are placed gives also the order in which they will be deposited one after another by decreasing voltages.

Basic elements				Acid elements		
Element	Per chemical equivalents, gram-cals.	Corresponding voltage	Element	Per chem. equiv., gram-cal.	Corresponding voltage	Salt
Li′	+62,900	+2.73	F_2'' (gas)	+52,900	+2.30	Fluoride.
Rb′	+62,000	+2.69	Cl_2'' (gas)	+39,400	+1.71	Chloride.
K′	+61,900	+2.69	Br_2'' (gas)	+32,300	+1.40	Bromide.
Ba″	+59,950	+2.60	Br′ (liquid)	+28,600	+1.20	Bromide.
Sr″	+58,700	+2.55	Br′ (solid)	+27,300	+1.18	Bromide.
Na′	+57,200	+2.48	I_2'' (gas)	+20,000	+0.87	Iodide.
Ca″	+54,400	+2.36	I′ (liquid)	+14,600	+0.63	Iodide.
Mg″	+54,300	+2.36	I′ (solid)	+13,200	+0.57	Iodide.
Al‴	+40,100	+1.74	S″ (solid)	− 5,100	−0.22	Sulphide.
NH_4'	+33,400	+1.45	Se″ (met.)	−17,900	−0.78	Selenide.
Mn″	+24,900	+1.08				
Zn″	+17,200	+0.75				
Fe″	+19,900	+0.47				
Cd″	+ 9,000	+0.39				
Co″	+ 8,200	+0.36				
Ni″	+ 7,700	+0.33				
Fe‴	+ 3,230	+0.14				
Sn″	+ 1,900	+0.08				
Pb″	+ 400	+0.02				
H′	0	0				
Tl″	− 900	−0.04				
Cu″	− 7,900	−0.34				
Hg″	−14,250	−0.62				
Pt⁗	−19,450	−0.84				
Ag′	−25,200	−1.10				
Au‴	−30,300	−1.32				

Calculation of Electromotive Force (Thomson's Rule)

One coulomb liberates 0.000010392 grams of H. In order to set free 1 gram of H, or 1 gram equivalent of any other element, an expenditure of 1 ÷ 0.000010392 = 96,600 coulombs is required. This is known as a Faraday and is usually denoted by the letter *F*.

If Q is the heat energy of formation of one molecular weight, n the valence of the compound, then

$$nEF = Q \times 4.19$$

or since

$$F = 96{,}600$$

$$E = \frac{Q}{23{,}040n} \text{ (Thomson's rule).}$$

The rule is not quite correct. The true relation between heat and electrical energy is given by the Gibbs-Helmholz equation

$$nEF = Q + T\frac{dE}{dT}$$

in which T = absolute temperature, and $\frac{dE}{dT}$ is the temperature coefficient of the e.m.f. As this coefficient is usually not large, Thomson's rule is sometimes used to give an approximate value.

Example:

$$Cu + Cl_2 + aq = 62{,}500;\ n = 2 \text{ valences}$$

$$E = \frac{62{,}500}{23{,}040 \times 2} = 1.36 \text{ volts}$$

$$CuSO_4 + H_2O = Cu + H_2SO_4 + O$$

$$197{,}500 + 69{,}000 - 210{,}000 = 56{,}300$$

$$E = \frac{56{,}300}{2 \times 23{,}040} = 1.22 \text{ volts}$$

Electroplating Baths[1]

Brass Bath (Roseleur's).—Per liter of water:

Sodium carbonate, dry (Na_2CO_3)	10 g.
Cupric acetate, pulverized	14 g.
Sodium bisulphite ($HNaSO_3$)	14 g.
Zinc chloride, fused ($ZnCl_2$)	14 g.
Potassium cyanide (100 per cent. KCN)	40 g.
Ammonium chloride (NH_4Cl)	2 g.

Current density, 0.3 amp. per sq. dm.; e.m.f., 2.7 volts; sp. gr., 1.0545; deposit per hour, 0.0041 mm.

Dissolve the sodium salts in 400 cc. warm water, stir the copper and zinc salts with 400 cc. of warm water, and stir slowly into the first solution. Dissolve the cyanide in the remainder of the water and stir into the other portion of the bath, where the precipitate should dissolve. Add the ammonium chloride and boil for an hour, replacing the water evaporated.

Copper Bath—Acid.—Per liter of water:

Copper sulphate ($CuSO_4 \cdot 5H_2O$)	200 g.
Sulphuric acid (conc. H_2SO_4)	30 g.

Current density, 1 to 3 amp. per sq. dm.; sp. gr. 1.1417.

[1] "A Laboratory Course in Electrochemistry," Watts.

Copper Bath—Alkaline.—Per liter of water:

Sodium sulphite (Na_2SO_3)	20 g.
Sodium carbonate ($Na_2CO_3 \cdot 10H_2O$)	20 g.
Sodium bisulphite ($HNaSO_3$)	20 g.
Cupric acetate ($Cu \cdot 2C_2H_3O_2 \cdot H_2O$)	20 g.
Potassium cyanide (100 per cent. KCN)	20 g.

Current density, 0.3 amp.; e.m.f., 2.9 volts; sp. gr., 1.0507; deposit in 1 hour, 0.0056 mm.; temp., 20°C.; make-up as under brass bath.

Cobalt Bath I.—Cobalt-ammonium sulphate, $CoSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O$, 200 grams per liter of water (or 145 grams of the anhydrous salt). Sp. gr., 1.053 at 15°C.

Cobalt Bath II.—Cobalt sulphate, $CoSO_4$, 312 grams, sodium chloride, NaCl, 19.6 grams, boric acid, nearly to saturation, water, 1000 cc. Sp. gr., 1.25 at 15°C.

Use cobalt anodes, and current even up to 100 amp. per square foot where possible (H. T. KALMUS *et al.*, *Electrical Review*, May 8, 1915).

Gold Bath.—Per liter of water:

Sodium carbonate, dry (Na_2CO_3)	10 g.
Gold-ammonium chloride $(NH_4)_2AuCl_6$	2 g.
Potassium cyanide	7 g.

Current density, 0.1 amp. per sq. dm.; e.m.f., 2.8 volts; sp. gr., 1.0175; deposit per hour, 0.00184 mm.; temperature, 20°C.; anode area one-third cathode.

Iron Bath.—Per liter of water:

Ferrous sulphate ($FeSO_4 \cdot 7H_2O$)	150 g.
Ferrous chloride ($FeCl_2 \cdot 4H_2O$)	75 g.
Ammonium sulphate $(NH_4)_2SO_4$	100 g.

Current density, 1.0 amp. This bath can be used for refining iron. At 20°C. the deposit is hard and brittle, but electrolysis at 80° to 90° yields a soft metal. See also p. 297.

Lead Bath.—Per liter of water:

Lead (as $PbSiF_6$)	50 to 80 g.
Hydrofluosilicic acid (H_2SiF_6)	100 to 150 g.
Gelatin	0.5 g.

Current density, 1.2 to 1.6 amp. per sq. dm. This bath is used for refining. For plating reduce the free acid to 2 or 3 per cent.

Nickeling on Iron or Steel.—Per liter of water:

Nickel-ammonium sulphate	75 g.

Current density, 0.3 amp.; e.m.f., 3.5 volts; sp. gr., 1.0479; deposit per hour, 0.0034 mm.; cast anodes should be half the area of cathode.

Nickeling on Brass or Copper.—Per liter of water:

Nickel sulphate ($NiSO_4 \cdot 7H_2O$)	50 g.
Ammonium chloride (NH_4Cl)	25 g.

Current density, 0.5 amp. per sq. dm.; e.m.f., 2.3 volts; sp. gr. 1.0357; deposit in 1 hour, 0.0059 mm.; cast anodes should be one-half area of cathode.

Nickeling on Zinc.—Per liter of water:

Nickel sulphate	40 g.
Sodium citrate	35 g.

Current density, 0.27 amp. per sq. dm.; e.m.f., 3.6 volts; sp. gr., 1.0394; deposit per hour, 0.00301 mm.; rolled anodes should have two and one-half times area of cathodes.

Nickel Solution—Thick Deposits.—Per liter of water:

Nickel sulphate, $NiSO_4 \cdot 7H_2O$	50 g.
Ammonium tartrate, neutral	36 g.
Tannin	0.25 g.

Current density, 0.3 amp. per sq. dm.

Black Nickel.—Per liter of water:

Nickel-ammonium sulphate	60 g.
Ammonium sulphocyanide	15 g.
Zinc sulphate, cryst.	7 g.

Use nickel anodes three to four times the surface of the cathodes. Current density, 0.05 amp. per sq. dm. Deposit takes best on white nickel. Solution must be kept neutral by nickel carbonate.

Platinum Bath—(ROSELEUR'S).—Per liter of water:

	Thin deposits	Thick deposits
Ammonium phosphate	20.0 g.	100.0 g.
Sodium phosphate	100.0 g.	100.0 g.
Platinum as $PtCl_4$	2.3 g.	10.0 g.

Current density, 1 to 2 amp. per sq. dm.; e.m.f., 3 to 4 volts.

Dissolve the platinic chloride in 100 cc. of water. Dissolve the ammonium phosphate in 200 cc. of water and stir into the platinum solution, when the precipitate previously formed will dissolve. Boil until odor of ammonia has disappeared and add water to make up for evaporation. Bath should have acid reaction and should be used hot. Potential difference, 6–8 volts.

Silver Bath—Heavy Plating.—Per liter of water:

Silver as silver cyanide	25 g.
Potassium cyanide	27 g.

Current density, 0.3 amp.; e.m.f., 1.3 volts; sp. gr., 1.0338; deposit per hour, 0.0114 mm.; area of anodes equals area of cathode.

Silver Bath—Ordinary Plating.—

Silver as silver cyanide	10 g.
Potassium cyanide	20 g.

Current density, 0.3 amp. per sq. dm.; e.m.f., 1.5 volts; sp. gr., 1.0175; deposit per hour, 0.0115 mm.

Tin Bath (ROSELEUR'S).—Per liter of water:

Sodium pyrophosphate	($Na_4P_2O_7$)	40 g.
Tin chloride, fused	($SnCl_2$)	16 g.
Tin chloride, cryst.	($SnCl_2 \cdot 2H_2O$)	4 g.

Current density, 0.3 amp. per sq. dm.; e.m.f., 2 volts; sp. gr., 1.0357; deposit per hour, 0.0059 mm.; anode area equal to cathode, solution gives deposit on copper, brass, bronze or zinc; but iron or steel must be coppered first or given a preliminary coat of tin by an immersion bath. The tin anodes do not corrode evenly and tin salts must be added to maintain sufficient amount of tin in solution.

Tin Baths.—Per liter of water:

		a	*b*	*c*
Caustic soda...........	($NaOH$)	90 g.	120 g.	125 g.
Tin chloride, cryst.......	($SnCl_2 \cdot 2H_2O$)	30 g.	30 g.	50 g.
Sodium hyposulphite....	($Na_2S_2O_3 \cdot 5H_2O$)	15 g.	60 g.	75 g.
Sodium chloride........	($NaCl$)	15 g..	.....	.....

Tin Bath, by Immersion.—Per liter of water:

Ammonium alum ($NH_4Al(SO_4)_2 \cdot 12H_2O$) .... 25 g.
Tin chloride, fused ($SnCl_2$).................... 2 g.

A bright coating is produced on clean iron by 30 to 60 seconds immersion in the boiling solution.

Zinc Bath.—Per liter of water:

Zinc sulphate ($ZnSO_4 \cdot 7H_2O$)................ 100 g.
Ammonium chloride (NH_4Cl)............... 25 g.
Ammonium citrate......................... 40 g.

Current density, 0.5 to 1.0 amp. per sq. dm.; e.m.f., 1.1 to 2.2; sp. gr., 1.0781; deposit per ampere-hour, 0.0173 mm.

Zinc Bath.—Per liter of water:

Zinc chloride.............................. 60 g.
Ammonium chloride......................... 30 g.
Hydrochloric acid.......................... 4 g.
Glycerine.................................. 4 g.

Use anodes of zinc and of antimonial lead in equal numbers.

Iron Bath—Cowper-Cowles Iron-Refining Process

Ferrous chloride and cresol-sulphuric acid (proportions not given). Iron oxide and scrap iron are kept in it constantly.

Electrolytic Oxidation and Reduction

Overvoltage of Hydrogen and Oxygen.

(Quoted from WATTS "A Laboratory Course in Electrochemistry.")

"Electrolysis lends itself well to oxidation and reduction processes, since it is possible to vary not only the speed, but also the intensity of the action with great nicety. Factors affecting the intensity of the reducing action are the material of the electrode, the nature of its surface, and the current density. In comparing the effects of different cathodes, an attempt is frequently made to resolve the reducing action of the cathodes into the catalytic action of the electrode material, and the 'overvoltage' of the

Overvoltage of Hydrogen

Cathode	By Caspari[1] $N \cdot H_2SO_4$	By Foerster and Pignet[2] $N \cdot H_2SO_4$		$2N \cdot H_2SO_4$ 0.125 amp. per sq. cm.	By Tafel[3] 0.1 amp. sq. cm.	Discharge potentials, $N.H_2SO_4$	
		Least potential	Current 0.04 amp. per sq. cm.			From Caspari	From Foerster
Mercury...	0.78	0.43	1.25	1.32	1.30	+.5476	+.1976
Zinc.......	0.70	......	....	......	....	+.4676	....
Lead.......	0.64	0.35	1.26	1.35	1.30	+.4076	+.1176
Tin.........	0.53	0.43	1.08	1.16	1.15	+.2976	+.1676
Cadmium..	0.48	0.48	1.18	1.23	1.22	+.2476	+.1976
Palladium..	0.46	......	....	......	....	+.2276	....
Copper.....	0.23	0.10	0.67	0.79	0.79	−.0024	−.1324
Nickel.....	0.21	0.10	0.64	0.74	0.74	−.0224	−.1324
Silver......	0.15	......	....	......	0.93(?)	−.0824	....
Platinum...	0.09	0.07	....	......	....	−.1424	−.1624
Gold.......	0.02	0.055	0.86	0.96	0.95	−.2124	−.1874
Platinized-platinum..	0.0	0.005	0.05	0.07	0.07	−.2324	−.2274

Note.—" N " in the above table stands for normal.

[1] *Zeit. phys. Chem.*, 1899, p. 89.

[2] *Zeit. f. Elektrochem.*, 1904, p. 715.

[3] *Zeit. f. Chem.*, 1904, p. 712.

hydrogen. The variation in the potential required by electrodes of different metals for visible evolution of hydrogen is usually expressed as the "overvoltage" of hydrogen on the particular metal, the least potential of platinized platinum being taken as zero. The discharge potentials referred to the calomel electrode (value, −0.56 volt) have been calculated for the difference between the calomel electrode and the hydrogen electrode in normal sulphuric acid. The increase of overvoltage with time and its diminution with rise of temperature varies for different metals.

Anode Potentials and Overvoltage of Oxygen

Anode	By Coehn. Least anode potential for evolution of O_2 vs. hyd. electrode in $N \cdot KOH$	Overvoltage Allmand, p. 131	Discharge potential vs. calomel electrode calculated by Watts	By Foerster. Least potential for evolution hyd. vs. hyd. electrode $2N \cdot KOH$	$2N \cdot KOH$ after 2 hours, 15°C.	$2N \cdot KOH$ 99°C.	$2N \cdot H_2SO_4 = 99°C.$
Nickel, sponge..	1.28	0.05	−0.9524	....	....	....	.....
Nickel, smooth..	1.35	0.12	−1.0224	1.35	2.00	1.77	.....
Cobalt.........	1.36	0.13	−1.0324	....	....	....	.....
Iron...........	1.47	0.24	−1.1424	1.47	2.02	1.89	.....
Platinized-platinum......	1.47	0.24	−1.1424	1.47	2.30	....	.....
Copper.........	1.48	0.25	−1.1524	....	....	....	.....
Lead...........	1.53	0.30	−1.2024	....	....	....	.....
Silver..........	1.63	0.40	−1.3024	....	....	....	.....
Cadmium.......	1.65	0.42	−1.3224	....	....	....	.....
Palladium......	1.65	0.42	−1.3224	1.65	2.45	....	.....
Platinum.......	1.67	0.44	−1.3424	1.67	2.92	2.50	2.17
Gold...........	1.75	0.52	−1.4224	....	....	....	.....

Electrochemical Order of the Elements[1]

In the following series each metal is electropositive to all that follow it. Two metals in contact in the presence of an electrolyte form a galvanic couple which causes the more electropositive to be decomposed by electrolysis.

Cs+, Rb, K, Na, Li, Ba, Sr, Ca, Mg, Al, Cr, Mn, Zn, Ga, Fe, Co, Ni, Tl, In, Pb, Cd, Sn, Bi, Cu, H, Hg, Ag, Sb, Te, Pd, Au, Ir, Rh, Pt, Os, Si, C, B, N, As, Se, P, S, I, Br, Cl, O, F.

Some authors put Cd just before Fe, Sn before Pb, and Sb and As before Cu. That the last two should precede copper ordinarily seems probable. The order changes with the specific electrolyte, and the position of selenium varies with the amount of illumination.

Potentials of Metals in their Normal Salts
(Neumann)

	Sulphate	Chloride	Nitrate	Acetate
Magnesium	+1.239	+1.231	+1.060	+1.240
Aluminum	+1.040	+1.015	+0.775	...
Manganese	+0.815	+0.824	+0.560	...
Zinc	+0.524	+0.503	+0.473	+0.522
Cadmium	+0.162	+0.174	+0.122	...
Iron	+0.093	+0.087	...	...
Cobalt	−0.019	−0.015	−0.078	−0.004
Nickel	−0.022	−0.020	−0.060	...
Tin	...	−0.085	...	...
Lead	...	−0.095	−0.115	−0.079
Hydrogen	−0.238	−0.249	...	−0.150
Bismuth	−0.490	−0.315	−0.500	...
Antimony	...	−0.376	...	...
Arsenic	...	−0.550	...	...
Copper	−0.515	...	−0.615	−0.580
Mercury	−0.980	...	−1.028	...
Silver	−0.974	...	−1.055	−0.991
Palladium	...	−1.066	...	...
Platinum	...	−1.140	...	...
Gold	...	−1.356	...	...

Decomposition Voltages
(Le Blanc)

H_2SO_4	1.67	NaI	1.12	$NiSO_4$	2.09		
HNO_3	1.69	$NaC_2H_3O_2$	2.10	$NiCl_2$	1.84		
H_3PO_4	1.70	K_2SO_4	2.20	$AgNO_3$	0.70		
HCl	1.31	KNO_3	2.17	$CdSO_4$	2.03	$SnCl_2$	1.76
NaOH	1.67	KCl	1.96	$CoSO_4$	1.92	$MnSO_4$	2.60
KOH	1.69	$(NH_4)_2SO_4$	2.11	$HgCl_2$	1.30	$MnCl_2$	2.77
NH_4OH	1.74	$CaCl_2$	1.89	$Fe_2(SO_4)_3$	1.64	$CuCl_2$	1.36
Na_2SO_4	2.21	$SrCl_2$	2.01	$FeSO_4$	2.02		
$NaNO_3$	2.15	$BaCl_2$	1.95	$AuCl_3$	0.39		
NaCl	1.98	$ZnSO_4$	2.35	$FeCl_2$	2.16		
NaBr	1.58	ZnBr	1.80				

[1] Gore, "The Art of Electrolytic Separation of Metals."

Electromotive Force of Metals and Minerals in KCN Solution[1]

$\frac{M}{1}$KCN = 6.5 per cent.

	Volts		Volts
Aluminum	+0.99	Iron	−0.17
Zinc, amalgamated	+0.93	Chalcopyrite	−0.20
Copper	+0.81	Pyrite	−0.28
Cadmium	+0.61	Galena	−0.28
Tin	+0.45	Argentite	−0.28
Bornite	+0.45	Speiss (cobalt)	−0.30
Copper, amalgamated	+0.39(?)	Arsenopyrite	−0.40
Gold	+0.37	Platinum	−0.40
Silver	+0.33	Cuprite	−0.43
Copper glance	+0.29(?)	Electric-light carbon	−0.46
Lead	+0.13	Blende	−0.48
Quicksilver	−0.09	Bournonite	−0.50
Gold, amalgamated	....	Coke	−0.52
Antimony	+0.06	Ruby silver ore	−0.54
Arsenic	+0.04	Stephanite	−0.54
Bismuth	....	Stibnite	−0.56
Niccolite	−0.11		

Decomposition Voltages of Molten Alkali Halides and Alkaline-earth Chlorides[2]

Compound	Decompound voltage	Temp. coeff.
LiCl	630° C. = 2.62 v.	1.35×10^{-3}
NaCl	835° C. = 2.6 v.	1.46×10^{-3}
KCl	810° C. = 2.8 v.	1.51×10^{-3}
NaBr	690° C. = 2.45 v.	1.465×10^{-3}
KBr	690° C. = 2.6 v.	1.465×10^{-3}
NaI	630° C. = 2.05 v.	1.48×10^{-3}
KI	630° C. = 2.2 v.	1.48×10^{-3}
Na_2SO_4	890° C. = 2.5 v.	2.00×10^{-3}
K_2SO_4	890° C. = 2.6 v.	2.00×10^{-3}
Na_2CO_3	770° C. = 1.3 v.	....
$CaCl_2$	585° C. = 2.85 v.	0.685×10^{-3}
$SrCl_2$	615° C. = 3.0 v.	0.715×10^{-3}
$BaCl_2$	650° C. = 3.05 v.	....

[1] Prof. S. B. Christy, *Trans.* A. I. M. E., Sept., 1899.
[2] B. Neumann and E. Bergve. *Z. Elektrochem.* **21**, 152–60 (1915).—For these experiments a C crucible covered with a mixture of water-glass and asbestos was found to be the only one practicable. Graphite electrodes were used covered, where exposed, with the same mixture.

Deposition by Immersion[1]

Solution	Deposits on	Does not deposit on
$SbCl_3$	Bi, Brass, German Ag, Pb, Sn, Zn	Sb, Cu, Fe, Ni, Au, Pt, Ag.
$BiCl_3$	Fe, Pb, Sn, Zn	Sb, Bi, Brass, Cu, Au, Pt, Ag.
$CuSO_4$, $Cu(NO_3)_2$	Fe, Pb, Sn, Zn	Sb, Bi, Cu, Au, Ni, Pt.
$CuCl_2$	Bi, Fe, Pb, Sn, Zn	Sb, Cu, Au, Ni, Pt, Ag.
$CuCl_2$ (ammoniacal).	Zn	Sb, Cu, Au, Bi, Fe, Pb, Ni, Pt, Ag.
$HgNO_3$	As, Bi, Cd, Cu, Sb, Fe, brass, Pb, Zn	
$AgNo_3$	Pb, Sn, Cd, Zn, Cu, Bi, Sb, Fe, Ni	Ag, Au, Pt.
$AgNo_2$ (alcoholic).	As, Sb, Bi, Zn, Sn, Cu, Fe.	
AgCN·KCN	Zn, Pb, Cu, brass, German Ag.	Sb, Bi, Sn, Fe, Ni, Ag, Au, Pt.
$Au(CN)_3KCN$	Zn, Cu, brass, German Ag.	Sb, Bi, Sn, Pb, Fe, Ni, Ag, Au, Pt.

Cleaning Metals by Electrolysis.—In cleaning adhesions of dirt, rust, etc., from metals, the following method is recommended: The articles are connected to the poles of an alternating circuit and immersed in a salt solution. The liberation of gases on the surface of the metals very quickly removes or loosens everything of a non-metallic character, while the alternating current prevents any permanent action on the metal itself, and it is said the finish of the surface is not interfered with. The voltage should be sufficient to cause evolution of gas at the poles, and currents up to 110 volts have been used. (*Mining Review*, Melbourne, Aust.)

[1] Gore, "Art of Electrolytic Separation of the Metals."

SECTION V

SAMPLING, ASSAYING AND ANALYSIS[1]

STANDARD SOLUTIONS

Ammonium-nitrate solution—for washing ammonium phosphomolybdate—5 to 10 per cent. Dissolve 50 to 100 grams NH_4NO_3 in water and acidify with HNO_3, using 1 cc. per liter excess. Or add ammonia to strong HNO_3 (sp. gr. 1.42) until alkaline to litmus, and bring back to acidity with HNO_3, using 1 cc. per liter excess.

Ammonium-oxalate solution—used chiefly as a precipitant for calcium. 1 gram of salt per 10 cc. of water. 1 cc. will then precipitate 0.0145 gram of CaO.

Barium chloride—used as precipitant for SO_3. 1 gram of crystals per 10 cc. of water. 1 cc. will precipitate 0.0327 gram SO_3.

Bichromate solution—for iron determination—8.79 grams pure $K_2Cr_2O_7$ in two liters of water. 1.0 cc. = 0.005 mg. Fe.

Cochineal—Grind 1 gram of the bugs in a mortar and digest with 100 to 150 cc. of cold dilute alcohol (1 vol. alcohol, 3 vol. water) for 20 or 30 min. Filter and the solution is ready for use. See note under phenolphthalein concerning acidity of alcohol. Useful with titrations with ammonia. Salts of copper, iron and aluminum must be removed. Color changes from yellowish red in acids to purple in alkalis.

Cuprous-chloride solution (ammoniacal)—for gas analysis. Weigh out 16 grams of fresh Cu_2Cl_2, or about 25 if it is old. Place in large Florence flask and add 250 cc. water. By means of delivery tube immersed in water, pass the gas from 200 cc. concentrated ammonia water into the Cu_2Cl_2 flask using a two-hole stopper in this flask with a check valve. Pass until practically all ammonia has passed over. 100 cc. of this Cu_2Cl_2 solution will absorb 24 cc. of CO but should not be used in second pipette after it has absorbed 6.

Cyanide solution—for copper determination. Use about 23 grams commercial potassium cyanide per liter of water. The theoretical amount is 20.63. 1.0 cc. = 0.005 gram Cu.

Ferrocyanide—for zinc determination—45 grams of pure K_4FeCy_6 per liter of water. 1.0 cc. = 0.010 gram Zn.

Hydrodisodium phosphate—HNa_2PO_4—used as precipitant for magnesia. 1 gram to 10 cc. of water. 1 cc. of solution precipitates 0.0112 gram of MgO.

Hyposulphite solution—for use in iodide copper determination—19.59 grams c.p. sodium hyposulphite per liter of water. 1.0 cc. = 0.005 g. Cu.

Litmus—Dissolve 1 gram of litmus in 100 cc. of hot water

[1] For data on qualitative analysis see the previous section, pp. 256–275 inc.

and add, drop by drop, dilute sulphuric acid until the liquid acquires a red color. Boil for 10 min. to expel the carbon dioxide. Should the red color pass into blue during the boiling, restore the color by adding a few drops of dilute sulphuric acid. Then add baryta water, drop by drop, until a violet color develops, set aside to deposit, and filter. Preserve the litmus tincture in bottles not completely filled, and preferably covered only with a loose cover.

Magnesia mixture—Dissolve 3 grams calcined MgO in least necessary quantity HCl. Add excess of magnesia and heat. Filter off any precipitated iron, alumina or phosphates and add 35 grams ammonium chloride and 25 cc. of strong ammonia, and dilute to 250 cc. 1 cc. = 0.016 gram P_2O_5 approximately.

Magnesium-nitrate solution—Dissolve 16 grams calcined magnesia in least necessary nitric acid. Add an excess of magnesia, heat for a few minutes, filter and make up 100 cc.

Manganese sulphate solution—for use in iron titrations, to render end-point more distinct. 160 grams of manganous sulphate are dissolved and diluted to 1750 cc. To this are added 330 cc. of phosphoric acid (syrup 1.7 sp. gr.) and 320 cc. of sulphuric acid. About 6 or 8 cc. are used in a titration.

Mercuric-chloride solution—for tin precipitation in iron analysis—7 grams $HgCl_2$ in 150 cc. water.

Methyl orange—Dissolve the dry substance in water, about 0.3 gram per liter. It must be used in cold solutions. It cannot, as a rule, be used with organic acids or with nitrites. Yellow with alkalis, pink with acids.

Molybdate solution—Dissolve 25 grams molybdic acid (MoO_3) in about 100 cc. ammonia water. If action is too slow, warm and add a little more strong ammonia water. Cool and pour solution, a little at a time, into about 300 cc. of HNO_3 (sp. gr. 1.20). Cool mixture during this process. Dilute to 500 cc. 1 cc. will precipitate about 0.001 gram of phosphorus.

For lead determination dissolve 9 grams of the salt in 1000 cc. water. 1.0 cc. = 0.01 gram Pb.

Nessler's solution—for estimation of ammonia in water analysis. Dissolve 50 grams potassium iodide in a small quantity of hot water, cool, and add with frequent agitation a strong solution of mercuric chloride (40 grams of $HgCl_2$ to 300 cc. of water until the red precipitate just redissolves. Filter. Add to the filtrate a strong solution of potassium hydrate containing 200 grams of the salt. Filter. Dilute to 1000 cc. and add 5 cc. of a saturated solution of mercuric chloride. Allow the precipitate to settle, decant the clear liquid and keep for use in a tightly stoppered bottle.

Normal acid or alkaline solutions—contain 1.008 grams of acid hydrogen or 17.008 grams of hydroxyl per liter.

Permanganate solution—for iron, lime, etc.—12 grams $KMnO_4$ to 2030 cc. water. 1 cc. = 10 mg. Fe. The same solution may be used for lime, 1 cc. = 5 mg. CaO; and for Mn, 1 cc. = 0.002946 gram Mn.

Phenolphthalein—The dry material is dissolved in alcohol, 5 grams per liter. The alcohol may have some acidity which can be removed by boiling, or by redistillation with lime. Cannot be used with ammonia or ammonium salts. Can be used for weak organic acids. Red with alkalis, colorless with acids.

Platinic chloride—Dissolve 1 gram of metal in *aqua regia*, evaporate to dryness, and dissolve in 1 cc. HCl and 9 cc. H_2O. 1 gram of this solution precipitates 0.048 gram of K_2O.

Salt solution—5.4189 grams per liter. 1.0 cc. = 0.01 mg. of silver. The salt should be dried at about 125°C.

Silver nitrate—1 gram per 20 cc. of water. 1 cc. precipitates 0.0104 gram of Cl.

Sodium chloride—See salt solution.

Stannous chloride solution—Heat 15 grams $SnCl_2$ and 1 gram pure Sn with 40 cc. water and 10 cc. conc. HCl. Keep tightly stoppered as it readily absorbs oxygen.

Starch paste—Rub 2 or 3 grams of starch with cold water to a smooth paste which is then added a little at a time to 400 or 500 cc. of boiling water into which it should be thoroughly stirred. After several minutes remove from heat and dilute (if necessary) to 600 cc. and add 5 grams of crystallized zinc chloride. Stir until the zinc salt dissolves, then allow to cool and settle. Decant and bottle the clear liquid for use.

Tannin—for use as indicator in lead assay by titration with ammonium molybdate. Dissolve 1 gram of tannin in 300 cc. water.

COMMON NAMES AND THEIR CHEMICAL EQUIVALENTS

Alum—usually the potassium-aluminum sulphate $KAl(SO_4)_2 \cdot 12H_2O$ is meant.

Argols—potassium bitartrate.

Baking soda—sodium bicarbonate.

Bleaching powder—$CaOCl_2$.

Bluestone—copper sulphate, $CuSO_4 \cdot 5H_2O$.

Calomel—mercurous chloride, Hg_2Cl_2.

Copperas—ferrous sulphate, $FeSO_4 \cdot 5H_2O$.

Corrosive sublimate—mercuric chloride, $HgCl_2$.

Epsom salts—magnesium sulphate.

Eschka's mixture—magnesium oxide and sodium carbonate.

Glauber's salts—sodium sulphate.

Green vitriol—ferrous sulphate.

Marignac's salt—potassium stannosulphate, $K_2Sn(SO_4)_2$.

Microcosmic salt—sodium-ammonium-hydrogen phosphate, $HNaNH_4PO_4 \cdot 4H_2O$.

Minium—red lead, Pb_3O_4.

Mohr's salt—$FeSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O$.

Muriatic acid—hydrochloric acid.

Oil of vitriol—sulphuric acid.

Orpiment—yellow arsenic glass.

Plaster of Paris—dehydrated gypsum, $CaSO_4$.

Realgar—red arsenic glass.

Rochelle salts—potassium-sodium tartrate, $KNaC_4H_4O_6 \cdot 4H_2O$.

Salt of Amber—succinic acid.

Sal ammoniac—ammonium chloride, NH_4Cl.

Salts of lemon—acid potassium oxalate, HKC_2O_4.

Salt cake—the residue from nitric-acid making, impure $HNaSO_4$.

Sal soda—sodium bicarbonate.

Schiff's reagent—ammonium thioacetate solution, $CH_3 \cdot COSNH_4$.

Seidlitz powders—35 grains of tartaric acid and a mixture of 40 grains of sodium bicarbonate with 120 grains of potassium and sodium tartrate.

Soluble water-glass—sodium silicate, Na_2SiO_3.

Sörensen's oxalate—sodium oxalate.

Sugar of lead—lead acetate.

Washing soda—sodium carbonate.

White vitriol—zinc sulphate, $ZnSO_4 \cdot 5H_2O$.

The Preparation of Proof Gold[1]

The purest gold which can be obtained (usually assay cornets) is dissolved in *aqua regia* and the excess of nitric acid expelled by repeated evaporation with additional hydrochloric acid on a water bath. The final solution is then poured in a thin stream into a large beaker full of distilled water, producing a solution of about 1 oz. of gold per pint of water. Stir vigorously and leave the solution to settle. At the end of about a week the chloride of silver will have subsided to the bottom. Remove the clear supernatant liquor with a glass siphon and dilute to about 1 oz. of gold per gallon of water. If the gold originally used was free from platinum, precipitate with sulphurous acid; if platinum was present, precipitate with oxalic acid. Sulphurous acid acts almost immediately, but if oxalic acid is used the solution should be warmed and allowed to stand for 3 or 4 days.

After the precipitated gold has settled the acid solution is siphoned off and the gold transferred to a large flask and repeatedly shaken with cold distilled water, closing the mouth of the flask with a watch-glass. The gold is then washed thoroughly with hot water and turned out into a porcelain basin, dried and melted in a clay crucible and poured into an iron mould, which should be neither smoked nor oiled, but rubbed with powdered graphite and then brushed clean with a stiff brush. The ingot is cleaned by brushing and heating in hydrochloric acid. It is then dried and rolled out. The rolls must be clean and bright and free from grease. The surface of the rolled gold plate is then cleaned by scrubbing with fine sand and ammonia, and also with hydrochloric acid, and is scraped with a clean knife before being used for proof in the bullion assay.

[1] T. K. Rose, "Metallurgy of Gold," fifth edition, p. 488.

Another method is given in the Memorandum by the Assayers of the Melbourne Mint, in the "Annual Report of the Mint," 1913, p. 138. Cornets of gold, derived from the metal obtained by reduction with sulphurous acid, and containing 0.1 per cent. of impurity (chiefly Ag), were treated with cold *aqua regia* (4:1), the solution largely diluted and allowed to stand for a week to effect separation of silver chloride. Three successive quantities of a dilute solution of silver nitrate (containing Ag 0.5 grain) were then added at intervals of 3 days, the surface of the liquid being gently stirred after each addition, and the whole was allowed to stand for 14 days. Any iridium or other impurity suspended in the liquid was entangled in the precipitated silver chloride; the clear solution was siphoned off, evaporated to dryness and ignited in porcelain; the sponge gold fused in a clay crucible with potassium bisulphate and nitrate, borax added, the melt allowed to cool, the cone of gold treated with boiling hydrochloric acid to remove adhering slag, placed by hand upon borax-glass contained in a clay crucible within a large, covered guard-pot, and melted under conditions precluding contamination of the metal by furnace dust. A slow current of chlorine was then passed through the molten metal for 1 hour, the gas being conducted through a clay tube (1/8-in. bore) by which the gold was continuously stirred. The charge was allowed to cool in the crucible, the cone of gold treated with boiling hydrochloric acid and finally rolled (with special precautions against contamination) into a fillet which was also treated with boiling acid. The original gold weighed 21.5 oz., the finished fillet 21.28 oz., and 0.204 oz. was subsequently recovered from the slag.

The Preparation of Proof Silver

Dissolve commercial fine silver in dilute nitric acid (1 : 1), and allow the liquid to stand until any fine gold has settled. Siphon off from the gold, dilute with hot water, precipitate the silver with hydrochloric acid, stir well, allow to settle, and wash thoroughly by decantation. When the decanted liquid no longer shows hydrochloric acid, which can be ascertained by testing it with a little silver nitrate, it may be considered clean. Allow the silver chloride to settle and decant off the solution. Transfer the silver chloride to a porous cup which has been soaked in hydrochloric acid and thoroughly washed afterward by standing in frequently changed distilled water. A cathode of pure silver or platinum is placed in the silver chloride and the porous cup immersed in a deeper one, in which a carbon anode is placed. Then a current is started, and silver chloride begins to reduce at the cathode. The outer liquid will become saturated with chlorine and should be renewed from time to time. The silver may then be melted down and rolled as given above under the head of gold. Another method is to use the best obtainable fine silver melted into the form of a cathode about 6 or 8 in. long, about 2 in. wide and 1/4 to 3/8 in. thick. Wrap this in filter paper so that no gold can be detached under

electrolysis. The electrolyte is about a 4 per cent. solution of silver nitrate slightly acidulated, and the cathode is pure silver. The current density should be such that the silver is deposited in the form of crystals, which should be later removed, melted and cast, although these crystals may be used themselves in the bullion proof. Still another method of preparing fine silver, due I believe, to A. E. Knorr, is to prepare a solution of silver nitrate from the best commercial fine silver obtainable (material which is already 999 fine) evaporate to remove the excess of nitric acid, and to the neutral solution add enough sodium carbonate to precipitate about one-tenth of the silver present. Boil the precipitate and solution thus produced for some time. The silver carbonate first formed precipitates all other impurities. Allow to settle, decant carefully (or filter).

The remainder of the silver is then precipitated by chemically pure sodium carbonate. This precipitate carries down a considerable amount of sodium carbonate, but when the material is melted down all of the sodium carbonate comes to the surface as a slag, and can be dissolved off with hydrochloric acid later. The silver carbonate will decompose without the addition of any other reagent if heated sufficiently. The bar produced in this way should be, as said above, cleaned with hydrochloric acid and then rolled, as given above under the head of the preparation of proof gold.

Assay Fluxes

Basic.—Sodium carbonate (Na_2CO_3)—best used in the anhydrous form.

Sodium bicarbonate ($HNaCO_3$)—less convenient than the above as it carries much less soda for the same bulk.

Potassium carbonate (K_2CO_3)—a mixture of sodium and potassium carbonates fuses at a much lower temperature than does either one alone.

Litharge (PbO)—forms exceedingly fusible silicates. Gives metallic lead with reducing agents, C, S, etc.

Red lead (Pb_3O_4)—same as above, but is more of an oxidizing agent. Carries silver into slag unless completely decomposed.

Lead peroxide (PbO_2)—still more energetic oxidizer.

Hematite (Fe_2O_3)—extremely infusible and must be reduced with carbon in presence of silica in order to work as a flux.

Lime (CaO)—when used with silica and some other base it forms fusible slags.

Sodium hydrate ($NaOH$)—used chiefly to decompose sulphides and sulphates, certain silicates and oxides, and organic compounds.

Acid.—Borax ($Na_2B_4O_7$)—should be fused before use to render it anhydrous. Has the property of holding almost all oxides in suspension.

Silica (SiO_2)—occasionally used with basic ores to lessen corrosion of crucibles. Better to use glass which carries about 80 per cent. SiO_2.

Glass—see silica.

Neutral.—Fluorspar (CaF_2)—is extremely fusible, and readily carries phosphates, etc., in suspension.

Common salt—also very fusible but does not dissolve infusible substances readily. Is mainly used as a cover to prevent oxidation of the charge underneath.

Metallic.—Iron—often used in the form of nails to take care of sulphur.

Lead—used in scorification assay both as a collector of the precious metals and, as it oxidizes, to take care of the gangue. In the crucible assay it is reduced from some oxide as a collector.

Oxidizing.—Niter (KNO_3 or $NaNO_3$)—at about red heat niter decomposes into potassium nitrite and oxygen, $KNO_3 = O + KNO_2$, at a higher temperature the nitrite also decomposes, $2KNO_2 = K_2O + 2NO + O$.

Lead peroxide (see under basic fluxes).

Manganese dioxide—must be used with some other base, and if any remains undecomposed it appears to carry silver into the slag.

Sodium peroxide—extremely energetic and forms very fusible slags. Especially good in decomposing tin ores, and sulphides, antimonites, etc.

Approximate Reducing Effect of Various Reducing Agents[1]

Reducing agent	Quantity of lead in grams reduced from litharge[2] by 1 gram of reagent
Wood charcoal	22–30
Powdered hard coal	25
Powdered soft coal	22
Powdered coke	24
Argol (crude tartar)	5 – 9.5
Cream of tartar	4.5– 6.5
Wheat flour	10.0–12.0
Starch	11.5–13.0
Sugar	12.0–14.5
Potassium cyanide	6
Antimonite	6
Blende	7–8
Copper pyrites	7–8
Fahlerz	7–8
Galena	3
Iron pyrites	11
Mispickel	7–8

In Assay Ton Charges

6 per cent.	FeS	reduces a 15-gram button.
8 per cent.	ZnS	reduces a 15-gram button.
7 per cent.	$CuFeS_2$	reduces a 15-gram button.
13 per cent.	Cu_2S	reduces a 15-gram button.
20 per cent.	PbS	reduces a 15-gram button.

[1] For amount of lead reduced from red lead multiply the factors given by 0.55.

[2] E. A. Smith's, "Sampling and Assay of the Precious Metals."

Oxidizing Agents (Wet)

Ammonium Nitrate.—Readily decomposes on heating.

Bichromates.—Usually used as the potassium salt.

Bromine.—Usually used as liquid.

Chlorine.—Generated from bleaching powder and sulphuric acid.

Chromates.—Usually used as the potassium salt.

Chlorates.—The sodium or potassium salt is used both in fusion and solution.

Hydrogen Peroxide.—A powerful oxidizer both in alkaline and acid solution.

Nitrates.—The sodium, potassium and ammonium salts are used.

Nitric Acid.—An extremely powerful reagent. The fuming acid is still more so and should be kept in a cool, dark place and handled carefully.

Permanganate.—The alkali-metal permanganates are energetic oxidizers both in acid and alkaline solution.

Peroxides (See also Hydrogen Peroxide).—Sodium and potassium peroxide are energetic agents in alkaline solution. The barium, manganese, lead and sodium peroxides are often used advantageously in fusion.

Reducing Agents

The chief reduction agents in fusions have been spoken of on p. 308. In solution we may use:

Alkaline.—Sodium amalgam, zinc dust, sodium sulphite, sugar, arsenious acid, sodium stannite.

Acid.—Zinc, iron, tin, aluminum, lead, stannous chloride, sulphur dioxide, sulphuretted hydrogen, hypophosphorous acid, oxalic acid, ferrous sulphate.

NITER REQUIRED TO OXIDIZE 1 PART OF METALLIC SULPHIDE

Sulphide	Parts niter to 1 of sulphide
Iron pyrites	2 –2½
Mispickel, copper pyrites, fahlerz, blende	1½–2
Antimonite	1½
Galena	⅔

STOCK FLUXES

	Sulphide ores	Tellurides I	Tellurides II	Blende	Tin ores
Litharge	8	10	30	50	60
Niter	1½	....	....	20	....
Potass. carb	....	....	7	....	....
Sodium carb	3	3	6	20	40
Borax glass	1½	6	5½	15	10
Sand	1½	....	....	5	....
Charcoal	....	0.11	....	....	1.5
Flour	....	....	1	....	....
Cover	Salt	Litharge	Litharge	Borax	Soda
Amount for ½ a.t. charge	8 a.t.	150 grams	75 grams	75 grams	125 grams

Table of Crucible Charges[1]

Ore	Character of gangue	A.t. ore	Grams lead flux	Grams $HNaCO_3$	Grams PbO	Grams K_4FeCy_6	Grams KNO_3	Grams SiO_2	Grams argol	Loop of iron wire	Grams borax glass	Cover	Remarks
Oxidized	Neutral, no Pb	½	30	....	25	....	....	....	....	....	....	Borax	
Quartz	No bases	½	.....	....	75	....	....	....	2	....	....	Borax	
Quartz	No bases	½	30	30	20	....	....	....	....	....	....	Salt	
Oxidized	Basic, no Pb	½	30–40	....	20	....	....	15	....	....	....	Borax	
Oxidized	Basic, with $BaSO_4$	½	40	20	25	....	....	15	....	2	....	Borax	
Galena	Lead, 84 per cent.	½	20	....	....	10	....	....	....	....	....	Salt	Heat gradually until mass subsides.
Galena	Siliceous, Pb 42 per cent.	½	15	20	20	....	5	....	....	....	....	Salt	
Lead carbonate	Neutral, Pb 40 per cent.	½	30	10	15	....	....	....	....	....	....	Borax	
Iron pyrites	None	¼	.....	35	20	....	5	15	....	6	....	Borax	Collect matte and scorify with the lead button.
Copper pyrites	Iron pyrites	½	.....	35	30	....	5	15	....	6	....	Borax	
Zinky ore	.....	⅓	.....	40	23	....	....	....	0–3	....	15	......	Nails if necessary.
Lead matte	.....	½	15	30	20	....	5	15	....	5	....	Borax	Wet-and-fire method preferable for silver.
Copper matte	.....	½	15	30	35	....	5	15	....	5	....	Borax	Wet-and-fire method preferable for silver.
Tellurides	Siliceous	½	30	30	40–80	....	....	....	....	....	....	Salt	Scorification preferable.
Tellurides	Siliceous	½	.....	....	80	....	....	....	2	....	....	Salt	Scorification preferable.
Arsenical	.....	½	.....	15	30	17	....	....	....	....	....	Salt	Scorification preferable.
Slags	.....	1	20	40	10	....	....	....	....	....	10	......	

Litharge Required to Flux Metallic Oxides[2]

One part of	As_2O_3	Cu_2O	CuO	Fe_3O_4	Sb_2O_3	ZnO	Fe_2O_3	MnO	SnO_2
Requires parts of PbO	1	1.5	1.8	4	5	8	10	10	13

[1] Furman, "Manual of Assaying."

[2] Hofman, "Metallurgy of Lead."

Cupel Absorption

A safe table for cupel absorption of lead buttons is given in ERNEST A. SMITH'S "Sampling and Assay of the Precious Metals."

Diameter of cupel, in.	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8
Absorption in grams	3	5	8	10	16	20	28	40

As to the cupel absorption of silver and gold, it seems unsafe to give any tables, as this varies with the nature of the material cupelled, the temperature, whether induced draft is used or not, and many other factors. It seems fairly safe to say that a small silver button will lose about 2 per cent., that at 100 mg. the loss will be about 1.5 per cent. and less for larger buttons, and that the gold loss will probably not run over 0.5 per cent., but these figures must be taken as approximations only. It must also be remembered that not all of the button remaining in the cupel is gold and silver. I have usually found about 0.3 per cent. of Pb and Bi as impurity in the silver button; with cement cupels I have found as much as 0.8 per cent. Pb and Bi. The factor is usually neglected in working on comparative tests on different cupels, although both DEWEY and I have repeatedly pointed it out.

W. J. Sharwood states (*Trans. A. I. M. E.*, 1915, page 1484) that "when a given amount of silver (or of gold) is cupeled with a given amount of lead, under a fixed set of conditions as to temperature, etc., the apparent loss of weight sustained by the precious metal is directly proportional to the surface of the button of fine metal remaining." From this he deduces that "the loss of weight varies as the 2/3 power of the weight, or as the square of the diameter of the button. The percentage loss varies inversely as the diameter of the button, or inversely as the cube root of the weight." This means that, if we run proof assays of any weight whatever, we can deduce the loss of a button of any other weight.

LEAD RETAINED IN THE CUPELLATION OF PLATINUM ALLOYS[1]

Composition of alloy			Lead retained, mg.	Character of button
Pt, mg.	Ag, mg.	Au, mg.		
100	......	....	37.5	Hard silvery.
100	25	....	31.0	Hard silvery.
100	50	....	26.2	Dull gray.
100	100	....	25.0	Dull gray.
100	101	48.0	24.0	Dull gray.
100	206	48.0	22.0	Smooth silvery.
100	206	6.0	10.0	Smooth silvery.
100	310	....	10.0	Slightly crystallized.
100	427	....	5.0	Smooth and silvery.
100	470	19.4	2.0	Smooth and silvery.

The lead is almost eliminated with 10 parts of silver to 1 of platinum.

[1] W. J. SHARWOOD, "*Journ. Soc. Chem. Ind.*," Apr. 30, 1904, p. 413.

Parting of Gold-Silver Alloys in Nitric Acid[1] after H. Carmichael[2]

Weight of metals used, milligrams			Ratio of metals			Weight of cornet,[3] Au+Pt	Weight of Pt in cornet[3]
Pt	Au	Ag	Pt	Au	Ag		
20	100	300	1	5	15	102.7	2.7
15	100	400	1	6.6	26.6	101.2 100.2	1.2 0.2
10	100	300	1	10	30	100.8 100.4	0.8 0.4
10	100	500	1	10	50	100.2	0.2
10	200	600	1	20	60	100.0	0.0
14	200	800	1	14.3	57.1	200.3	0.3
14	300	900	1	21.4	64.3	300	0.0
7	100	400	1	14.3	57.1	100.2	0.2
5	100	500	1	20	100	100	0.0

[1] The first acid was of 1.16 sp. gr., the second of 1.26.
[2] Taken from Smith's "Sampling and Assay of the Precious Metals" as were also the next two tables.
[3] The author seems to assume a 100 per cent. gold recovery. This is by no means a sure matter, and all the errors of work are thrown on the results for platinum, which are therefore open to suspicion.

Solubility of Platinum-Silver Alloys in Nitric Acid

Composition of alloy		Parted in HNO_3 of 1.10 sp. gr.		Parted in HNO_3 of 1.40 sp. gr.	
Pt, per cent.	Ag, per cent.	Platiniferous residue,[1] per cent.	Pt dissolved,[2] per cent.	Platiniferous residue,[1] per cent.	Pt dissolved,[2] per cent.
0.5	99.5	0.42	0.08	0.22	0.28
1.0	99.0	0.85	0.15	0.42	0.58
2.0	98.0	1.74	0.26	1.09	0.91
3.0	97.0	2.19	0.81	1.81	1.19
4.0	96.0	2.98	1.02	2.42	1.58
5.0	95.0	3.56	1.44	2.62	2.38
10.0	90.0	....	....	4.53	5.47
13.0	87.0	3.33	9.67	5.79	7.21
14.0	86.0	4.26	9.74	4.97	9.03
15.0	85.0	4.32	10.68	7.93	7.07
16.0	84.0	4.55	11.45	11.54	4.46
18.0	82.0	4.53	13.46	11.65	6.35
20.0	80.0	....	....	13.94	6.06
25.0	75.0	16.62	8.38	20.66	4.34
30.0	70.0	....	....	29.29	0.71
31.5	68.5	33.58	[2]	....	....

[1] Contains Pt and Ag.
[2] Apparently these figures were arrived at by difference and they are probably unreliable for large weights of residue. See the table following.

Solubility of Platinum-Silver Alloys in Nitric Acid of 1.10 Sp. Gr. (Thompson and Miller's Table)[1]

Composition of alloy		Total residue, per cent.	Silver in residue, per cent.	Platinum in residue, per cent.	Platinum dissolved, per cent.[1]
Pt, per cent.	Ag, per cent.				
10.39	89.61	3.86	0.27	3.59	6.80
20.59	79.41	8.58	1.81	6.77	13.82
31.46	68.54	36.59	12.09	24.50	6.96
37.89	62.11	49.13	13.64	35.49	2.40
57.05	42.95	65.16	12.19	52.79	4.08

Highly Refractory Crucibles

According to Deville a particularly refractory crucible can be made by heating alumina and strongly ignited marble in equal proportions to the highest temperature of the wind furnace, and then using equal proportions of the substance thus obtained with powdered ignited alumina and gelatinous alumina.

Lime crucibles are made by taking a piece of well-burned slightly hydrated lime, cutting it by means of a saw into a rectangular prism 3 or 4 in. on the side and 5 or 6 in. high. The edges are rounded off, and a hole is bored in the center.[2]

Magnesia Crucibles.—George Weintraub[3] of the General Electric Company, of Schenectady, N. Y., makes refractory articles of magnesia, alumina, thoria, etc., without the use of a binder. The magnesium oxide is first heated in an electric furnace to a high temperature in order to let it assume a stable condition. This firing causes the magnesia to cake together so that regrinding is necessary. It is ground to the fineness of flour in a tube mill. A mould is then made for the article to be produced, say, a crucible. This mould is made of carbon or graphite and a layer of the powdered magnesia is placed on the bottom. A carbon or graphite plug is now placed centrally in the crucible upon this magnesia layer. It is surrounded by a layer of paper which permits the magnesia to shrink when heated. When moulding a crucible of 2½ in. inside diameter, a paper of from 1/16 to ⅛ in. thickness is suitable. The space between the walls of the mould and the paper-covered core is then filled with magnesia powder and packed to a certain degree by shaking and bumping. The mould is now placed in an electric furnace and heated to about 1500°C. When finished and the mould is cooled, the walls of the magnesia crucible contract upon the layer of loose paper carbon, so that cracking is

[1] The solubility of these platinum-silver alloys seems to depend upon the strength of acid used, how the alloy has been annealed, and the amount of gold present, if any.

[2] Sexton, "Fuel and Refractory Materials."

[3] *Metallurgical and Chemical Engineering*, Vol. 10, p. 308.

avoided. The finished crucibles are smooth, homogeneous and strong and may be safely handled and may even be worked on the lathe. Tubes may be made in the same way.[1]

Analyses of Graphite Crucibles[2]

	1	2	3	4	5	6	7	8
SiO_2	25.91	27.22	33.44	34.03	32.67	37.09	31.40	31.31
Al_2O_3	11.26	7.03	15.70	12.95	11.52	14.58	19.57	17.30
Fe_2O_3	0.48	0.51			2.79		1.78	
Ca, Mg, O	tr	tr	.....	.....	.....	.....	1.10	.....
Graphite	58.24	62.54	48.15	50.18	48.68	44.40	42.08	47.40
Water	2.77	2.42	0.77	1.63	1.50	2.92	1.20	3.42
	98.66	99.72	98.06	98.79	97.16	98.99	97.13	99.43

Weights to be Taken in Sampling Ore[3]

Weights		Diameters of largest particle					
Grams	Pounds	Very low grade of uniform ores, mm.	Low grade ores, mm.	Medium ores		Rich ores, mm.	Rich and spotty ores, mm.
				Mm.	Mm.		
....	20,000.0	207.0	114.0	76.2	50.8	31.6	5.4
....	10,000.0	147.0	80.3	53.9	35.9	22.4	3.8
....	5,000.0	104.0	56.8	38.1	25.4	15.8	2.7
....	2,000.0	65.6	35.9	24.1	16.1	10.0	1.7
....	1,000.0	46.4	25.4	17.0	11.4	7.1	1.2
....	500.0	32.8	18.0	12.0	8.0	5.0	0.85
....	200.0	20.7	11.4	7.6	5.1	3.2	0.54
....	100.0	14.7	8.0	5.4	3.6	2.2	0.38
....	50.0	10.4	5.7	3.8	2.5	1.6	0.27
....	20.0	6.6	3.6	2.4	1.6	1.0	0.17
....	10.0	4.6	2.5	1.7	1.1	0.71	0.12
....	5.0	3.3	1.8	1.2	0.80	0.50	....
....	2.0	2.1	1.1	0.76	0.51	0.32	....
....	1.0	1.5	0.80	0.54	0.36	0.22	....
....	0.5	1.0	0.57	0.38	0.25	0.16	....
90.0	0.2	0.66	0.36	0.24	0.16	0.10	....
45.0	0.1	0.46	0.25	0.17	0.11	....	....
22.5	0.05	0.33	0.18	0.12	....	....	....
9.0	0.02	0.21	0.11	....	....	....	....
4.5	0.01	0.15	....	....	....	....	....
2.25	0.005	0.10	....	....	....	....	....

[1] U. S. Patent, 1,022,011, April 2, 1912.

[2] Kerl, "Handbuch der gesammten Thonwaaren Industrie."
1, 2, Hesse; 3, Rhenish; 4, Düsseldorf; 5, German crucible after 18 heats; 6, London (Morgan); 7, English; 8, American.

[3] Richards, "Ore Dressing," Vol. II.

Size-Weight Ratio in Sampling[1]

Diameter of largest particle, inches	Minimum weight of sample, pounds Colorado practice
0.04	0.0625
0.08	0.50
0.16	4.00
0.32	32.00
0.64	256.00
1.25	2,048.00
2.50	16,348.00

Smallest Permissible Weight for Samples of a Given Size[2]

Size, inches cube or mesh	Weight of sample, lb.	Ratio of weight of largest cube to weight of sample	Effect on value created by one cube assaying $100,000 per ton, of sp. gr. 5
2	10,000	1: 7,000	$14.42
1½	5,000	1: 8,300	12.17
1	2,000	1: 11,000	9.00
¾	1,000	1: 13,000	7.50
½	400	1: 18,000	5.62
⅜	300	1: 31,000	3.17
¼	200	1: 71,000	1.40
3/16	100	1: 83,000	1.20
⅛	75	1: 220,000	0.44
6 mesh	50	1: 430,000	0.23
10 mesh	25	1: 930,000	0.107
18 mesh	10	1:1,900,000	0.051
30 mesh	4	1:4,200,000	0.023
50 mesh	1	1:5,500,000	0.018

Scheme for Sampling Rich Ores with Vezin Samplers[3]

	Inches	Sample, per cent.	Lb. in 100 tons
Maximum size of cubes.	1.00	0.20	40,000
Maximum size of cubes.	0.25	1.25	2,500
8 mesh..............	0.0625	0.785	157
30 mesh..............	0.0171	0.005	10

[1] E. A. Smith, "Sampling and Assay of the Precious Metals."
[2] R. H. Richards, "Ore Dressing," Vol. III.
[3] R. H. Richards, "Ore Dressing," Vol. III.

Coal Sampling[1]

SIZE OF SLATE CONTAINED IN COAL, AND SIZE OF ORIGINAL SAMPLE REQUIRED TO INSURE THE ERROR OF SAMPLING BEING LESS THAN 1 PER CENT.

Size of slate, inches	Weight of largest piece of slate, lb.	Original sample should weigh, lb.
4	6.7	39,000
3	2.5	12,500
2	0.75	3,800
1½	0.38	1,900
1¼	0.24	1,200
1	0.12	600
¾	0.046	230
½	0.018	90

SIZE TO WHICH SLATE AND COAL SHOULD BE BROKEN BEFORE QUARTERING SAMPLES OF VARIOUS WEIGHTS

Weight of sample to be divided, lb.	Should be broken to, inches	Weight of sample to be divided, lb.	Should be broken to, inches
7500	2	40	2 mesh
3800	1½	5	4 mesh
1200	1	½	8 mesh
460	¾	¼	10 mesh
180	½	....	....

Coke Sampling[2]

A point that is of utmost importance in the sampling of coke for blast-furnace use is the ash determination, since every pound of ash in a ton of coke means more expensive fluxing, increased cost of smelting, useless cinder and less furnace capacity available for the production of metal. For this reason differences of opinion as to the ash content of coke for blast-furnace use often cause bitter controversies.

In an investigation of this subject several years ago, I was surprised to find how much of the apparent ash content of coke was due to foreign material introduced in the process of grinding the sample. For instance, the analysis of a sample reported as containing 17 per cent. of ash showed that one-seventeenth of this ash, or 1 per cent. of the weight of the sample, was iron abraded from a BRAUN pulverizer, while the ordinary cast-iron bucking-board and muller much used in grinding samples to be tested introduces iron into the sample to the extent of from ½ to 3 per cent.

[1] *Journ. Ind. and Eng. Chem.*, p. 161, 1909.
[2] Excerpts from an original article in "Coal Age," July 24, 1915.

Whether the grinding be done by machinery or by hand, this introduction of foreign matter in grinding can be cut down greatly by the use of manganese- or chrome-steel grinding plates.

It is impossible to determine the amount of this contamination with a magnet, for the reason that too much coke dust will adhere to the iron filings. It is necessary to treat the sample with a neutral copper-sulphate solution, agitate thoroughly, filter and wash the residue with hot water until entirely free from soluble copper salts. This residue is now dried and ignited and the ash tested for copper or the coke treated directly with nitric acid to dissolve the copper. The weight of copper precipitated by the iron in this process is then calculated from the ratio of their respective atomic weights.

This method will not answer for the determination of any foreign material introduced by pebble mills, but is very effectual where the grinding surfaces are of iron. It may be objected that the original ash of the coke may have contained some iron which has been reduced to the metallic state by the red-hot carbon of the coke during the coking process. In answer to this argument, any iron in the coke is probably present as ferrous oxide and combined with silica to form ferrous silicate ($FeSiO_3$). But in any event the objection is not valid, because if the coke sample is crushed in a silica-pebble mill or in an agate mortar, the iron in the coke does not react with neutral copper-sulphate solution.

Limit beyond Which Samples Should not be Divided when Crushed to Different Sizes in Laboratory

Size of coal mesh	Should not be divided to less than, grams	
2	8300	
4	1100	
8	120	Should be pulverized to at least 60 mesh.
10	55	
20	3	

ETCHING REAGENTS AND THEIR APPLICATIONS[1]

Etching Reagents for Iron and Steel

Copper-Ammonium Chloride.—Usually consists of a 10 per cent. solution of the salt in water, and is suitable for wrought iron and mild steel. The specimen is immersed in the solution for about 1 minute, then washed, and the copper deposit, which is readily detached, wiped off under running water. This reagent is used for deep etching effects, and also to darken parts rich in phosphorus.

Copper Chloride.—Dilute acidulated copper chloride in

[1] O. F. Hudson, "Iron and Steel Institute," March, 1915.

alcohol is used by STEAD to detect phosphorus in steels. The reagent is made up as follows:

Copper chloride	10 grams.
Magnesium chloride	40 grams.
Hydrochloric acid	20 cc.

The salts are dissolved in the least possible quantity of water, and the solution made up to 1000 cc. with alcohol. The purer portions of the steel become coated with copper before the phosphoric portions.

Hydrochloric Acid.—A dilute solution (1 per cent.) in ethyl alcohol is generally used. HOYT (c) writes that a solution of 1 cc. hydrochloric acid (sp. gr. 1.19) in 100 cc. absolute alcohol "is recommended for all the iron-carbon alloys whether in a hardened or annealed state," while the action can be accelerated (for special steels) by the addition of a few cubic centimeters of a 5 per cent. solution of picric acid in alcohol.

Iodine.—The ordinary tincture should be used. A simple solution in absolute alcohol is not so suitable. The specimen may be immersed in the solution, or a drop or two placed on the surface to be etched, and allowed to remain until decolorized.

Nitric Acid.—Until the introduction of picric acid, a dilute solution of nitric acid was the principal etching agent for iron and steel, and it is still often used. Solutions (up to about 5 per cent.) in water, or, preferably, alcohol, are generally used. When alcohol is the solvent, absolute alcohol should be used for washing the specimen, and not water. LANTSBERRY (c), who always uses nitric acid for steels, points out that the success of the method depends on thoroughly washing the specimen with alcohol and drying at once, and that the surface should never be moistened with water.

SAUVEUR (c) writes that for all grades of steel, wrought iron, and pig iron, regardless of treatment, he uses solutions of concentrated nitric acid in absolute alcohol, in proportions varying between 1 and 10 per cent. of acid, according to requirements. He prefers it to picric acid. The samples are washed in absolute alcohol and dried by means of an air-blast. For manganese steel he uses 10 per cent. nitric acid in absolute alcohol, leaving the specimen in the bath until it is covered with a black deposit. It is then washed in alcohol, without any attempt at removing the deposit by rubbing.

HOWE (c) uses a solution of 2 per cent. of concentrated nitric acid in water for hardened steels, manganese steels, etc., and also occasionally to develop grain boundaries quickly in low-carbon material, although he notes that it roughens up the ferrite much more than picric acid. He recommends a preliminary treatment for the removal of grease, using "alcohol, hydrochloric acid in alcohol, or, best, picric acid in alcohol."

A 4 per cent. solution of nitric acid in iso-amyl alcohol (as suggested by KOURBATOFF) is also used, and gives a slow and delicate etching.

(c) Information specially communicated for this paper.

Picric Acid.—This reagent, introduced by Ischewsky, is the one most commonly used, generally as a saturated or nearly saturated solution in alcohol. The specimen is immersed for times varying with the kind of steel and the effect desired, from a few seconds for light etching of ordinary rolled or annealed steels and cast irons, to several minutes for hardened steels and wrought irons. Picric acid is sometimes used in conjunction with nitric acid. Thus Desch (*c*) recommends for all ordinary (unhardened) steels alcoholic picric acid to which a few drops of nitric acid have been added. A solution of picric acid in amyl alcohol is also used for a slow etching. L. Archbutt (*c*) also finds it "an advantage to add a small quantity of nitric acid, which gives greater certainty of etching, especially in cold weather." The solution he uses contains 80 vols. of picric acid in alcohol and 20 vols. of 2 per cent. nitric acid in alcohol.

Rosenhain's and Haughton's Reagent consists of:

Ferric chloride	30 grams
Hydrochloric acid (conc.)	100 cc.
Cupric chloride	10 grams
Stannous chloride	0.5 grams
Water	1000 cc.

It is used for determination of the distribution of phosphorus in steel, the purer portions of the steel being stained by deposition of copper, leaving the phosphorus-rich portions white.

Of the numerous other reagents some are used for special purposes, such as sodium picrate, for the detection of cementite; while others are more or less complicated solutions, such as Kourbatoff's reagent, consisting of 3 vols. of a saturated solution of *o*-nitrophenol in alcohol and 1 vol. of a 4 per cent. solution of nitric acid in alcohol, used for the determination of troostite and sorbite in hardened steels.

Electrolytic Etching

This method is of great value in special cases. Generally a solution of a neutral salt is used as the electrolyte; the specimen is made the anode and a piece of platinum foil the cathode. A feeble current of a small fraction of an ampere is used. Desch (*c*) finds that etched figures in brasses, etc., are most perfectly developed by electrolytic etching, using a 5 per cent. sodium-chloride solution and a platinum cathode with two dry cells. Other electrolytes used are ammonium nitrate, sodium thiosulphate (used by Le Chatelier for copper-tin alloys), ammonia, and sometimes very dilute acid solutions.

For Monel metal, L. Archbutt (*c*) "obtained very good results by electrolytic etching in a solution containing 45 cc. dilute sulphuric acid (1:3) and 5 cc. hydrogen peroxide solution, using a current of 0.1 amp. and 0.5 volt, etching for about 50 seconds. A slight staining of the specimen was subsequently removed by light rubbing with a dilute solution of bromine in hydrochloric acid." Constantan was etched in a similar way, "but stains were removed by using a mixture of dilute sulphuric

acid and hydrogen peroxide and rubbing with the finger." ROSENHAIN (c) has also found that electrolytic etching is useful for nickel-copper alloys.

Polish Attack.—Used with such success by OSMOND and it is one which, if not always applicable, is not adopted as widely as it should be. The objections which appear to be urged against the method are (a) the difficulty of getting uniformly good results, and (b) the danger of obscuring the structure by the flowing action of polishing. Neither of these objections need, however, be serious; the former is overcome by experience, while the latter is probably largely imaginary, unless altogether unnecessary pressure is used. The procedure which has been found suitable for copper and its alloys has already been described in dealing with ammonia as an etching agent. For steels OSMOND used a very gentle etching reagent, such as a 2 per cent. solution of ammonium nitrate with precipitated calcium sulphate in parchment, but this method is not now so often used. The author, however, for iron and steel, makes use of parchment thoroughly soaked in water on which a paste of precipitated calcium sulphate is spread. The specimen is then alternately lightly etched with picric acid, and rubbed gently for a few seconds on the parchment. Frequently also it is found to be an advantage to etch the specimen lightly, then polish very gently with alumina and re-etch, repeating if necessary.

GWYER (c) finds that polish attack is sometimes very effective for light aluminum alloys, "for example, in bringing out the structure of the iron-aluminum eutectic. For this washed and ignited magnesia is required, the polishing being done on parchment kept moistened with very dilute caustic soda solution."

GULLIVER (c) notes that sometimes a good polish attack may be obtained with water alone, although not if the pad is new. He found, for example, that polish attack with water alone was defective in the case of bismuth-tin alloys.

Heat-tinting.—Although not perhaps, strictly speaking, an etching process, heat-tinting is a valuable and widely used method of revealing the structure of alloys, and especially for the detection of small differences in concentration of solid solutions. It consists in heating the specimen until a thin film of oxide is formed on the surface, differences in composition giving rise to variations in thickness, and hence variations in color of the film. STEAD used it with great advantage in studying phosphoric cast irons and alloys of iron and phosphorus, and showed that by its use phosphide and carbide of iron could readily be distinguished, while HEYCOCK and NEVILLE proved its value in their work on the copper-tin alloys. STEAD has also applied the method to the determination of the distribution of phosphorus in steel. In a paper on "Metallographic Methods for the Detection of Phosphorus in Steel," read before the Cleveland Society of Engineers in December last, STEAD gives details of the heat-tinting method suitable for this purpose. The specimen is floated on a bath of molten tin at a temperature of about 300°C., and allowed to remain until the whole surface

has a reddish-brown color. On examining the specimen, the portions richest in phosphorus will be detected by their blue color, since the parts which are richer in phosphorus than the surrounding metal become colored more quickly. The preliminary treatment of the specimen before it is raised to the tinting temperature is important. Washing with a 1 per cent. solution of picric acid in alcohol is recommended, and the surface should always be "cleaned by rubbing with a clean piece of linen or cotton. The specimen is heated to about 150°C., and then rubbed with a clean piece of chamois leather while still hot." It is then immediately raised to the tinting temperature.

Instead of heating in air, and obtaining a colored oxide film, STEAD has shown that other atmospheres may be used, such as sulphuretted hydrogen or bromine. The use of an atmosphere containing bromine for the examination of MUNTZ metal has been described recently by STEAD.

Heat-tinting appears to require considerable experience in order to obtain consistent results, and the author, among others cannot rely upon it to be uniformly successful. The following is a summary of the principal reagents for particular metals and alloys.

Etching Reagents Suitable for Particular Metals and Alloys

The following list gives the principal reagents which have been found especially suitable for different metals and alloys:

Copper.—Ammonia (sp. gr. 0.88, diluted 1:1 with water), ammonium persulphate (10 per cent. aqueous solution), bromine (followed by a wash with ammonia), copper-ammonium chloride (5 grams of copper-ammonium chloride in 100 cc. of water, add ammonia until precipitate just dissolves).

Brasses.—Ammonia, ammonium persulphate, copper-ammonium chloride, electrolytic etching, ferric chloride (slightly acidulated with HCl), chromic acid (saturated or nearly saturated solution), nitric acid (strong acid, followed by water), Tinoféef's reagent (94 grams HNO_3 and 6 grams Cr_2O_3, a few drops are used in 50 cc. of water).

Bronzes.—Ammonia, ammonium persulphate, ferric chloride.

Copper-Aluminum Alloys (Aluminum Bronzes).—Ammonium persulphate, ferric chloride, copper-ammonium chloride, nitric acid.

German Silver.—Ammonium persulphate, ferric chloride.

Nickel-Copper Alloys, Monel Metal.—Electrolytic etching.

Gold and Rich Gold Alloys, Platinum and Its Alloys.—*Aqua regia* (dilute, 1 part HNO_3, 5 parts HCl, 6 parts distilled water, used at 15°C.).

Aluminum and Light Aluminum Alloys.—Caustic soda, hydrochloric acid, hydrofluoric acid (1 part fuming HF to 10 or 20 parts of water, clear after treatment by a few second's immersion in HNO_3).

Lead, Tin and Their Alloys (White Metal, etc.).—Chromic acid in nitric acid, ferric chloride, hydrochloric acid, nitric acid, silver nitrate (5 per cent. solution).

Zinc and Alloys Rich in Zinc.—Caustic soda, iodine (1 part iodine, 3 parts KI and 10 parts water).

GRAVIMETRIC FACTORS

	Given	Sought	Multiply by factor N
Aluminum, 27.1	Al_2O_3	Al	0.5303
	Al	Al_2O_3	1.8856
	$AlPO_4$	Al_2O_3	0.4187
	Al_2O_3	$Al_2(SO_4)_3$	3.3504
Antimony, 120.2....	Sb_2O_4	Sb	0.7900
	Sb_2O_4	Sb_2O_3	0.9474
	Sb_2O_4	Sb_2O_5	1.0526
	Sb_2S_3	Sb	0.7142
	Sb_2S_3	Sb_2O_3	0.8569
	Sb_2S_3	Sb_2O_5	0.9520
	Sb	Sb_2O_3	1.1998
	Sb	Sb_2O_5	1.3330
Arsenic, 74.96	As_2S_3	As	0.6091
	As_2S_3	As_2O_3	0.8041
	As_2S_3	As_2O_5	0.9341
	As_2S_3	AsO_4	1.1291
	As_2S_5	As	0.4832
	$Mg_2As_2O_7$	As	0.4827
	$Mg_2As_2O_7$	As_2O_3	0.6373
	$Mg_2As_2O_7$	As_2O_5	0.7403
	$Mg_2As_2O_7$	AsO_4	0.8949
	Ag_3AsO_4	As	0.1620
	As	As_2O_3	1.3202
	As	As_2O_5	1.5336
Barium, 137.37	$BaSO_4$	Ba	0.5885
	$BaSO_4$	BaO	0.6568
	$BaCrO_4$	Ba	0.5422
	$BaCrO_4$	BaO	0.6053
	$BaCO_3$	Ba	0.6960
	$BaCO_3$	BaO	0.7771
	Ba	BaO	1.1165
Bismuth, 208.0	Bi_2O_3	Bi	0.8966
	BiOCl	Bi	0.8017
	BiOCl	Bi_2O_3	0.8942
	Bi_2S_3	Bi	0.8122
	Bi_2S_3	Bi_2O_3	0.9061
	Bi	Bi_2O_3	1.1154
Boron, 11..........	B_2O_3	B	0.3143
	B	B_2O_3	3.1818
Bromine, 79.92	AgBr	Br	0.4256
	AgBr	HBr	0.4309
	Br − Cl	Br	1.7969
	Br − Cl	AgBr	4.2202
	Br	$O_{1/2}$	0.1001

GRAVIMETRIC FACTORS

	Given	Sought	Multiply by factor N
Cadmium, 112.4....	CdO	Cd	0.8754
	CdS	Cd	0.7780
	CdS	CdO	0.8888
	Cd	CdO	1.1424
Caesium, 132.81....	Cs_2SO_4	Cs	0.7344
	Cs_2PtCl_6	Cs	0.3943
	Cs	Cs_2O	1.0623
Calcium, 40.07	CaO	Ca	0.7146
	CaO	$CaCO_3$	1.7847
	$CaSO_4$	Ca	0.2943
	$CaSO_4$	CaO	0.4119
	$CaCO_3$	Ca	0.4005
	$CaCO_3$	CaO	0.5603
	Ca	CaO	1.3993
	Ca	$CaCO_3$	2.4971
	CaO	CaC_2O_4	2.2841
Carbon, 12.........	CaC_2O_4	CO_2	0.3436
	$CaCO_3$	CO_2	0.4397
	CO_2	C	0.2727
	C	CO_2	3.6667
	CO_2	CO_3	1.3636
Chlorine, 35.46.....	$AgCl$	Cl	0.2474
	$AgCl$	HCl	0.2544
	Ag	Cl	0.3287
	Cl	$O_{1/2}$	0.2256
	$AgCl$	$O_{1/2}$	0.05581
Chromium, 52.0....	Cr_2O_3	Cr	0.6842
	Cr_2O_3	CrO_3	1.3158
	$PbCrO_4$	Cr	0.1609
	$PbCrO_4$	Cr_2O_3	0.2351
	$PbCrO_4$	CrO_3	0.3094
	Cr	Cr_2O_3	1.4615
	Cr	CrO_3	1.9230
Cobalt, 58.97	$CoSO_4$	Co	0.3804
	Co_3O_4	Co	0.7343
	Co	CoO	1.2713
	$Co(NO_2)_3 \cdot 3KNO_2$	Co	0.1303
Copper, 63.57	CuO	Cu	0.7989
	Cu	CuO	1.2517
	Cu_2S	Cu	0.7986
	Cu_2S	CuO	0.9996
	$CuSCN$	Cu	0.5226
	$CuSCN$	CuO	0.6541

GRAVIMETRIC FACTORS

	Given	Sought	Multiply by factor N
Cyanogen, 26.01	AgCN	CN	0.19427
	Ag	CN	0.2411
Fluorine, 19........	CaF_2	F	0.4867
	SiF_4	F	0.7286
Gold, 197.2.........	Au	$AuCl_3$	1.5395
Hydrogen, 1.008.....	H_2O	H	0.11190
Iodine, 126.92......	AgI	I	0.54055
	PdI_2	I	0.7041
	I − Cl	I	1.3877
	I − Cl	AgI	2.5673
Iron, 55.84	Fe_2O_3	Fe	0.6994
	Fe_2O_3	FeO	0.8998
	Fe_2O_3	Fe_3O_4	0.9666
	Fe_2O_3	FeS_2	1.5028
	FeO	Fe	0.7773
	FeO	Fe_2O_3	1.1114
	FeS	Fe	0.6352
	Fe	FeO	1.2865
	Fe	Fe_2O_3	1.4298
Lead, 207.2	$PbSO_4$	Pb	0.6832
	$PbSO_4$	PbO	0.7360
	$PbSO_4$	PbO_2	0.7887
	$PbSO_4$	PbS	0.7890
	$PbCrO_4$	Pb	0.6411
	$PbCrO_4$	PbO	0.6906
	PbS	Pb	0.8660
	PbS	PbO	0.9328
	$PbCl_2$	Pb	0.7450
	PbO	Pb	0.9283
	Pb	PbO	1.0772
Lithium, 6.94	Li_2SO_4	Li	0.13474
	Li_2SO_4	Li_2O	0.29007
	Li_3PO_4	Li	0.18197
	Li	Li_2O	2.1527
	Li_2CO_3	Li	0.1879
	Li_2CO_3	Li_2O	0.4044
Magnesium, 24.32..	$Mg_2P_2O_7$	Mg	0.2184
	$Mg_2P_2O_7$	MgO	0.3621
	$Mg_2P_2O_7$	$MgCO_3$	0.7572
	$MgSO_4$	Mg	0.20201
	$MgSO_4$	MgO	0.33491
	MgO	Mg	0.6032
	MgO	$MgCO_3$	2.0912
	Mg	MgO	1.6579

GRAVIMETRIC FACTORS

	Given	Sought	Multiply by factor N
ıese, 54.93...	$Mn_2P_2O_7$	Mn	0.3869
	$Mn_2P_2O_7$	MnO	0.4996
	Mn_3O_4	Mn	0.7203
	Mn_3O_4	MnO	0.9301
	MnS	Mn	0.6314
	MnS	MnO	0.8153
	$MnSO_4$	Mn	0.3638
	$MnSO_4$	MnO	0.4697
	MnO	MnO_2	1.2256
	Mn	MnO	1.2913
	Mn	MnO_2	1.5826
y, 200.6....	HgS	Hg	0.8622
	HgS	HgO	0.9309
	HgCl	Hg	0.8498
	HgCl	HgO	0.9176
	Hg	HgO	1.0798
enum, 96.0.	MoO_3	Mo	0.6667
	$PbMoO_4$	MoO_3	0.3922
58.68.......	$NiSO_4$	Ni	0.3792
	NiO	Ni	0.7858
	Ni	NiO	1.2727
n, 14.01....	NH_4Cl	N	0.26186
	NH_4Cl	NH_3	0.31838
	NH_4Cl	NH_4	0.33722
	$(NH_4)_2PtCl_6$	N	0.06310
	$(NH_4)_2PtCl_6$	NH_3	0.07672
	$(NH_4)_2PtCl_6$	NH_4	0.08126
	$(NH_4)_2PtCl_6$	NH_4Cl	0.2410
	Pt	N	0.1435
	Pt	NH_3	0.1745
	Pt	NH_4	0.1848
	N	NH_3	1.2158
	NH_3	N	0.82247
	N	$(NH_4)_2O$	1.8587
	N	$(NH_4)_2SO_4$	4.7164
	N	N_2O_5	3.8579
	N	NO_3	4.4261
	N	NO_2	3.2841
	N	NO	2.1420
ɔrus, 31.04..	$Mg_2P_2O_7$	P	0.2787
	$Mg_2P_2O_7$	P_2O_5	0.6379
	$Mg_2P_2O_7$	PO_4	0.8534
	$FePO_4$	P_2O_5	0.4708
	$U_2P_2O_{11}$	P_2O_5	0.1989

Gravimetric Factors

	Given	Sought	Multiply by factor N
Phosphorus, 31.04..	P_2O_5	P	0.4369
	P	P_2O_5	2.2886
Platinum, 195.2....	$(NH_4)_2PtCl_6$	Pt	0.4396
	K_2PtCl_6	Pt	0.4015
Potassium, 39.10...	KCl	K	0.5244
	KCl	K_2O	0.63170
	KBr	K	0.3285
	K_2SO_4	K	0.44870
	K_2SO_4	K_2O	0.5405
	K_2PtCl_6	K	0.1609
	K_2PtCl_6	K_2O	0.1941
	K_2PtCl_6	KCl	0.3071
	$KClO_4$	K	0.28219
	$KClO_4$	K_2O	0.33992
	$KClO_4$	KCl	0.53811
	K	K_2O	1.2046
	KOH	K_2CO_3	1.2315
Rubidium, 85.45...	Rb_2SO_4	Rb	0.6401
	Rb_2PtCl_6	Rb	0.2952
	Rb	Rb_2O	1.0936
Selenium, 79.2.....	Se	SeO_2	1.4040
	Se	SeO_3	1.6060
Silicon, 28.3.......	SiO_2	Si	0.4693
	SiO_2	SiO_3	1.2653
	SiO_2	Si_2O_7	1.3980
	SiO_2	SiO_4	1.5307
	Si	SiO_2	2.1308
Silver, 107.88......	AgCl	Ag	0.7526
	AgCl	Ag_2O	0.80843
	AgBr	Ag	0.57444
	AgI	Ag	0.4595
	Ag	Ag_2O	1.0742
Sodium, 23.00	NaCl	Na	0.3934
	NaCl	Na_2O	0.53028
	Na_2SO_4	Na	0.3238
	Na_2SO_4	Na_2O	0.4364
	Na_2CO_3	Na	0.43396
	Na_2CO_3	Na_2O	0.58491
	Na	Na_2O	1.3478
Strontium, 87.63...	$SrSO_4$	Sr	0.4770
	$SrSO_4$	SrO	0.5641
	$SrCO_3$	Sr	0.5936
	$SrCO_3$	SrO	0.7019
	Sr	SrO	1.1826

Gravimetric Factors

	Given	Sought	Multiply by factor N
Sulphur, 32.07.....	$BaSO_4$	S	0.13738
	$BaSO_4$	SO_2	0.27446
	$BaSO_4$	SO_3	0.34300
	$BaSO_4$	SO_4	0.41154
	$BaSO_4$	H_2SO_4	0.42018
	S	SO_2	1.9978
	S	SO_3	2.4967
	S	H_2SO_4	3.0585
Tellurium, 127.5...	Te	TeO_2	1.2510
	Te	TeO_3	1.3765
Thallium, 204.0....	TlI	Tl	0.6165
	Tl_2PtCl_6	Tl	0.5000
	Tl	Tl_2O	1.0392
Thorium, 232.4....	ThO_2	Th	0.8790
Tin, 118.7	SnO_2	Sn	0.7877
	Sn	SnO_2	1.2693
Titanium, 48.1	TiO_2	Ti	0.6005
Tungsten, 184.0 ...	WO_3	W	0.7930
Uranium, 238.2....	U_3O_8	U	0.8481
	U_3O_8	UO_2	0.9525
	UO_2	U	0.8816
Vanadium, 51.0....	V_2O_5	V	0.5604
	V	V_2O_5	1.7843
	V	VO_4	2.2549
Zinc, 65.37........	ZnO	Zn	0.8034
	ZnS	Zn	0.6709
	ZnS	ZnO	0.8351
	$Zn_2P_2O_7$	Zn	0.4289
	Zn	ZnO	1.2448
Zirconium, 90.6....	ZrO_2	Zr	0.7390
Ammonia, 17.03 ...	Pt	NH_3	0.17452
	Pt	NH_4	0.1848
	Pt	NH_4OH	0.35912

Calculated by International Atomic Weight Table of 1915, O = 16.

Properties of Precipitates[1]

Elements	Object	Obtained by or precipitated with	Obtained or precipitated as	Conditions of solution	Soluble in	Contaminants	Prepared for weighing by	Weighed as
K	Weighing.	Precipitant $PtCl_4$. Precipitate preferably dissolved in hot H_2O and evaporated in a weighed vessel.	K_2PtCl_6	Cold, alcoholic, containing chlorides or HCl. Salts other than NaCl should be absent. Small amounts of Ca or Mg may be present, but are detrimental.	Slightly soluble in cold, more so in hot, H_2O. Solubility increased by alkali or acid, diminished by $PtCl_4$ or Na_2PtCl_6.	NaCl and other salts (as sulphates) insoluble in alcohol. Removed by washing with $H_2O + NH_4Cl + K_2PtCl_6$.	Drying.	K_2PtCl_6
	Weighing.	Precipitant $PtCl_4$.	K_2PtCl_6	As above.	As above.	As above.	Ignition gently at first. Addition of $H_2C_2O_4$ aids reduction.	Pt
	Weighing.	Evaporation and gentle ignition. Volatile at temperatures above a dull red.	KCl	Only chlorides or salts converted into chlorides should be present. Ammonium salts may be present.	In water. Less in alcohol or strong HCl.	NaCl, and if long exposed to the air, organic dust.	Ignition not above a dull red.	KCl
	Weighing.	Evaporation and ignition. $(NH_4)_2CO_3$ facilitates conversion.	K_2SO_4	Absence of salts forming non-volatile sulphates or containing non-volatile acids (as H_3PO_4).	Moderately in H_2O, much less in alcohol.	Na_2SO_4 or other non-volatile sulphates.	Ignition over an ordinary Bunsen flame.	K_2SO_4
Na	Weighing.	Evaporation and gentle ignition.	NaCl	Same as KCl.	Same as KCl.	KCl and other salts (as sulphates insoluble in alcohol).	Ignition not above a dull red.	NaCl

[1] Compiled mainly from an article by Prof. E. Waller, entitled "Properties of Precipitates," *School of Mines Quarterly*, Vol. XII, taken from Furman's "Manual of Practical Assaying."

	Weighing.	Same as K_2SO_4.	Na_2SO_4	Same as K_2SO_4.	Same as K_2SO_4.	K_2SO_4 and other non-volatile sulphates.	Same as K_2SO_4.	Na_2SO_4
Ca	Weighing.	Precipitant $(NH_4)_2C_2O_4$ or $H_2C_2O_4$ in NH_4OH solution.	CaC_2O_4	Hot, strongly ammoniacal and an excess of oxalate.	Mineral acids, slightly in $H_2C_2O_4$.	MgC_2O_4, which is removed by solution in HCl and reprecipitation.	Ignition, gently at first and finally over blast-lamp.	CaO
	Weighing.	As above.	CaC_2O_4	As above.	As above.	As above.	Addition of H_2SO_4, evaporation, and ignition. In presence of C add HNO_3.	$CaSO_4$
	Separation.	Precipitant $(NH_4)_2CO_3$.	$CaCO_3$	Alkaline solution free from large excess of alkaline salts, especially citrates.	H_2O containing CO_2. In acids and in hot solution of NH_4Cl. Insoluble in $H_2O + NH_4OH + (NH_4)_2CO_3$.	$BaCO_3$ and $MgCO_3$, if much are present.		
Mg	Weighing.	Precipitant Na_2HPO_4.	$MgNH_4PO_4$	Cold, containing excess of $NH_4OH + NH_4Cl$. Absence of SiO_2 and bases other than alkalies.	Acids. Hot solutions and slightly in cold H_2O. Insoluble in NH_4NO_3.	SiO_2 and $Mg(OH)_2$.	Ignition, gently at first, finally intensely. In presence of C add NH_4NO_3.	$Mg_2P_2O_7$
	Separation.	Precipitant $Ba(OH)_2$.	$Mg(OH)_2$	Akaline and moderately concentrated. Free from ammonium salts and organic salts.	Acids and ammonium salts. Prevented by organic salts.	Usually unimportant for purposes of separation.		
Ba	Weighing.	Precipitant H_2SO_4. Should be heated before adding.	$BaSO_4$	Hot, containing some free HCl. Absence of SiO_2, large amounts of $(NH_4)_2S$ group and Ca salts.	Conc. H_2SO_4 in strong hot HCl and HNO_3 (dilute). In strong hot Fe_2Cl_6 and in alkaline or al-	Alkaline and alkali-earth chlorides, chlorates, sulphates, nitrates, basic, ferric, or aluminic com-	Ignition. In the presence of C the addition of HNO_3 is necessary.	$BaSO_4$

PROPERTIES OF PRECIPITATES. *Continued*

Elements	Object	Obtained by or precipitated with	Obtained or precipitated as	Conditions of solution	Soluble in	Contaminants	Prepared for weighing by	Weighed as
Ba					kali-earth nitrates. In citrates.	pounds. Repeated boiling in very dilute HCl assists in removal, but liable to dissolve some of the precipitate. $MgCO_3$ if much is present, and carbonates of the fixed alkalies.		
	Separation.	Precipitant $(NH_4)_2CO_3$.	$BaCO_3$	Alkaline, containing NH_4OH and excess of $(NH_4)_2CO_3$.	H_2O containing CO_2 and acids. In hot NH_4Cl. Insoluble in $NH_4OH + (NH_4)_2CO_3$.			
Fe	Weighing.	Precipitant NH_4OH. Addition of NH_4Cl aids precipitation.	$Fe_2(OH)_6$	Alkaline, and free from H_2S.	Mineral acids and solutions containing citric, tartaric acids, etc., or organic substances (as sugar).	Basic ferric salts Cr, P_2O_5, Al, Mn, Zn, Co, Ni, Mg, SiO_2, etc.	Ignition. In presence of C, HNO_3 or NH_4NO_3 should be added. Volatile in presence of chlorides.	Fe_2O_3
	Separation.	As above.	$Fe_2(OH)_6$	As above.	As above.	As above.		
	Separation.	Precipitant $NaC_2H_3O_2$. Filtered hot.	$Fe_2(OH)_n(C_2H_3O_2)_{6-n}$	Dilute containing but little free $HC_2H_3O_2$. Hot, but too long boiling should be	In cold mineral acids. Also in citrates or organic substances. Insolu-	Salts of fixed alkalies, SiO_2, P_2O_5, Al, Cr, Co, Ni, Zn, Mn, Cu, etc. Removed by resolu-		

Fe				avoided.	ble in hot very dilute $HC_2H_3O_2$.	tion and reprecipitation.		
Al	Weighing.	Precipitant (usual) NH_4OH. Best precipitated by adding slight excess NH_4OH, boiling, and passing H_2S.	$Al_2(OH)_6$	Neutral or slightly alkaline, containing preferably NH_4Cl.	Acids and fixed alkalies. Slightly in cold NH_4OH. Tartrates, citrates, sugar, etc., prevent precipitation.	Basic Al salts; SiO_2, P_2O_5, Al, Cr, Co, Ni, Zn, Mn, etc. Removed by resolution and reprecipitation.	Ignition. Slightly volatile in presence of NH_4Cl.	Al_2O_3
	Separation.	Same as Fe.	$Al_2(OH)_n(C_2H_3O_2)_{6-n}$	Same as Fe. No free acetic acid should be present.	Same as Fe, except slightly soluble in hot dilute $HC_2H_3O_2$.	Same as Fe.		
Cr	Weighing.	Precipitant NH_4OH. Excess removed by boiling.	$Cr_2(OH)_6$	Absence of members of the $(NH_4)_2S$ group, and preferably all non-volatile salts. Solution must be neutral.	All acids, in NaOH, KOH, and slightly in NH_4OH. Tartrates, citrates, sugar, etc., prevent precipitation.	Same as Al.	Ignition.	Cr_2O_3
Ti	Weighing.	Insoluble form by boiling the solution acidified with H_2SO_4.	H_2TiO_3	Dilute containing but little free H_2SO_4. HCl and chlorides must be absent. $HC_2H_3O_2$ facilitates precipitation. Prolonged boiling also.	Soluble form same as $Fe_2(OH)_6$. Insoluble form by fusion with $KHSO_4$ or boiling with conc. HCl or H_2SO_4.	Fe_2O_3, Al_2O_3, SiO_2, and P_2O_5; Fe_2O_3 and Al_2O_3 removed by re-solution, reduction with SO_2, and reprecipitation in presence of $HC_2H_3O_2$.	Ignition with addition of $(NH_4)_2CO_3$.	TiO_2
	Separation.	Fusion and leaching until filtrate runs cloudy.	(xNa_2O, TiO_2)-Na_2TiO_3	Long fusion with Na_2CO at high temperature.	Acids. Slightly in H_2O.	Fe_2O_3, acid-sodium silicate, alkali-earth carbonates, etc.		

PROPERTIES OF PRECIPITATES. *Continued*

Elements	Object	Obtained by or precipitated with	Obtained or precipitated as	Conditions of solution	Soluble in	Contaminants	Prepared for weighing by	Weighed as
Zn	Weighing.	Precipitant Na_2CO_3.	$2ZnCO_3$, $Zn(OH)_2$	Absence of caustic and bicarbonate alkalies and ammonium salts.	Dilute acids, fixed caustic alkalies, bicarbonates, and organic solutions.	Alkaline carbonate removed by repeated washing with hot H_2O. Fe_2O_3, Al_2O_3, and SiO_2 removed by solution and precipitation of the ignited ZnO.	Ignition; absence of C is necessary.	ZnO
	Separation.	Precipitant H_2S in boiling dilute $HC_2H_3O_2$ solution. NH_4Cl facilitates precipitation.	ZnS, H_2O	Alkaline, or acid only with weak organic acid. Free mineral acids prevent precipitation (H_2SO_4 least). Fe should be absent.	Dilute HCl and HNO_3, strong H_2SO_4 when hot. Free NH_4OH retards precipitation.	Mn, Co, and Ni sulphides. Removed by resolution, neutralizing, and reprecipitation. Fe if not previously removed.		
Mn	Weighing.	Precipitant $NaNH_4HPO_4$ in presence of ammonium salts.	$MnNH_4PO_4$	Mn must be entirely in manganous form, and slightly alkaline. An excess of phosphate is necessary. Oxalates and excessive amounts of ammonium salts should be absent.	Acids. Slightly in large excess of ammonium salts. The influence of ammonium salts is lessened by large excess of the precipitant.	None if bases forming insoluble phosphates are absent and precipitate is well washed.	Ignition. Gently at first.	$Mn_2P_2O_7$
	Separation.	Br from acetate solution $KClO_3$ from boiling nitric-acid solution.	MnO_2	Absence of HCl or other halogen acids. Also lower oxides of nitrogen or reducing agents. Boiling necessary.	Dilute mineral acids (especially HCl). Insoluble in strong $HC_2H_3O_2$ and conc. HNO_3.	Salts of fixed alkalies, Fe_2O_3, ZnO.		

Ni	Weighing.	Electrolysis.	Ni	Absence of all other metals of H_2S and $(NH_4)_2S$ groups. Ni present as oxalate, sulphate, or double ammonium nitrate, and excess of NH_4OH.	Readily in HNO_3. Slowly in strong $(NH_4)_2C_2O_4$.	Co, Fe and Zn, unless previously separated.	Drying at gentle heat. (See Cu.)	Ni
	Weighing.	Precipitant KOH or NaOH.	$Ni(OH)_2$	Bases other than fixed alkalies should be absent.	Mineral acids. In ammonium salts, tartrates, citrates, etc.	Alkalies, Fe_2O_3, Al_2O_3, and SiO_2 from reagents.	Ignition strongly.	NiO
	Separation.	Precipitant H_2S in weak $HC_2H_3O_2$ solution.	NiS, H_2O	Absence of other members of the H_2S or $(NH_4)_2S$ groups. NH_4Cl aids precipitation.	Precipitation prevented by moderate amounts of free acetic or mineral acids. Soluble in mineral acids and KCN.	Sulphides of H_2S and $(NH_4)_2S$ groups, if not previously removed.		
Co	Weighing.	Precipitant KNO_2 in solution slightly acid with $HC_2H_3O_2$.	$6KNO_2$, Co_2, $(NO_2)_6$	Warm, containing only Co, Ni, and K salts, and nearly saturated with $KC_2H_3O_2$.	H_2O, acids, NH_4 and Na salts. Insoluble in dilute $HC_2H_3O_2$ and alcohol.	Ca and Pb if present. K salts should be removed by careful washing.	Dissolve in dilute H_2SO_4, and evaporate in a weighed vessel. Ignition.	$3K_2SO_4 + 2CoSO_4$
	Weighing.	Electrolysis.	Co	Same as Ni.	Same as Ni.	Same as Ni.	Same as Ni.	Co
	Separation.	Same as NiS, H_2O.	CoS, H_2O	Same as NiS, H_2O.	Same as NiS, H_2O.	Ni and other members of $(NH_4)_2S$ group, if not previously removed by separation.		
Cu	Weighing.	Electrolysis.	Cu	H_2SO_4 solution containing a few drops of HNO_3	HNO_3 and HCl. Deposit prevented by Cl,	As, Sb, or Bi, if HNO_3 is not present. If HNO_3 and	Washing with H_2O and then with alcohol.	Cu

PROPERTIES OF PRECIPITATES. *Continued*

Elements	Object	Obtained by or precipitated with	Obtained or precipitated as	Conditions of solution	Soluble in	Contaminants	Prepared for weighing by	Weighed as
Cu				preferable. Organic acids should be absent.	too strong acid, or lower oxides of nitrogen.	Zn are present, Zn will begin to precipitate as soon as Cu is all precipitated.	Drying at a temperature which can be borne by the hand.	
	Separation.	Precipitant H_2S in dilute acid solution.	CuS	Moderately strong HCl or H_2SO_4. If HNO_3 is present, the solution must be cold and dilute.	Hot dilute HNO_3 and strong hot HCl.	Other members of the H_2S group.		
Pb	Weighing.	Precipitant H_2SO_4.	$PbSO_4$	Excess of H_2SO_4, and but little HNO_3 or HCl. NH_4 salts and salts of organic acids must be absent.	Conc. mineral acids; in $Na_2S_2O_3$; in NH_4 salts, and especially those of organic acids.	Other sulphates, which are removed by washing with very dilute H_2SO_4.	Ignition. If C is present, treat with HNO_3 + H_2SO_4, evaporate, and ignite.	$PbSO_4$
	Weighing.	Precipitant $K_2Cr_2O_7$ in acetic-acid solution.	$PbCrO_4$	Bi, Ag, Fe, and Ba should be absent. Chlorides should be absent, and also alkaline citrates, tartrates, etc.	Moderately strong mineral acids; in hot $NH_4C_2H_3O_2$. Insoluble in dilute HNO_3.	Ba, Bi, Hg and chromates. If much Fe is present, possibly $Fe_2(CrO_4)_3$.	Drying on previously weighed filter.	$PbCrO_4$
	Separation.	Precipitant H_2S.	PbS	Slightly acid, neutral, or alkaline. Best precipitated in cold H_2SO_4 solution.	Dilute boiling HNO_3; hot conc. HCl. In $Na_2S_2O_3$.	Other members of the H_2S group if present.		

Ag	Weighing.	Precipitant HCl in very slight excess.	AgCl	Slightly acid with HNO_3 free from chlorides.	Partially in strong hot HCl or HNO_3. Partially in alkaline and alkaline-earth chlorides. Readily in NH_4OH, KCN, and $Na_2S_2O_3$.	Chlorides of Pb and Hg if present in the solution.	Ignition until the edges fuse. Volatile at a temperature slightly above dull red.	AgCl
	Separation.	Precipitant NaBr.	AgBr	Same as AgCl.	Same as AgCl. Insoluble in considerable excess of precipitant.			
As	Weighing.	Precipitant H_2S in HCl.	As_2S_3	Acid with mineral acid (preferably HCl).	Soluble in alkaline hydrates, carbonates, and sulphides. In $KHSO_3$, in aqua regia, and in $H_2O + Cl$ or $H_2O + Br$.	Other sulphides of H_2S group if present.	Drying. Volatile as As_2S_3 upon ignition.	As_2S_3
	Weighing.	Precipitant $MgCl_2$ in ammoniacal solution containing alcohol.	$MgNH_4AsO_4$	Alkaline with NH_4OH, containing a minimum of NH_4Cl and 30 per cent. alcohol.	In warm acids. In $H_2O + NH_4Cl$. Insoluble in $NH_4OH +$ alcohol.	Basic Mg salts, sulphates, and other salts insoluble in $NH_4OH +$ alcohol.	Dissolving the precipitate in HNO_3 into a weighed vessel, evaporating, and igniting slowly at first.	$Mg_2As_2O_7$
Sb	Weighing.	Precipitant H_2S in acid solution, or upon acidifying solutions of sulphantimonite.	Sb_2S_3	Slightly acid and moderately dilute.	Moderately concentrated acids (HCl especially). Tartaric acid assists precipitation. Dissolved by fixed alkalies or alkaline sulphides.	S generally accompanies the precipitate; removed by replacing the H_2O by alcohol, and washing with CS_2.	Mixed with 50 times its weight of HgO and ignited to dull red.	Sb_2O_4

PROPERTIES OF PRECIPITATES. *Continued*

Elements	Object	Obtained with or precipitated by	Obtained or precipitated as	Conditions of solution	Soluble in	Contaminants	Prepared for weighing by	Weighed as
Sn	Weighing.	Precipitant H_2S in acid solution or upon acidifying solutions of alkaline sulpho-stannate.	SnS_2	Moderately dilute and slightly acid. Precipitation promoted by acetates and interfered with by oxalates or oxalic acid.	Moderately strong acids (HCl especially). In boiling solution containing free $H_2C_2O_4$.	Other members of H_2S group, if present. Separated from Sb_2S_3 by adding $H_2C_2O_4$, and boiling.	Heating moderately and slowly with free access of air. Addition of HNO_3 aids conversion.	SnO_2
P	Weighing.	$MgCl_2$ in ammoniacal solution containing NH_4Cl.	$MgNH_4PO_4$	Same as Mg.	Same as Mg.	Same as Mg.	Same as Mg.	$Mg_2P_2O_7$
	Separation and titration.	Precipitant $(NH_4)_2MoO_4$ in HNO_3 solution heated to 80°C. Agitation facilitates precipitation.	$12MoO_3$-$(NH_4)_3$-PO_4	Acid with HNO_3, and containing an excess of NH_4NO_3 and precipitant. Chlorides, HCl, reducing agents and organic acids should be absent.	NH_4OH and alkalies. Soluble in HCl and moderately strong H_2SO_4 or HNO_3. In hot H_2O. Insoluble in very dilute HNO_3 containing NH_4NO_3.	Arseno-molybdate, SiO_2, Fe_2O_3, and TiO_2.	For titration by dissolving in NH_4OH and reducing by Zn + H_2SO_4, or by acidimetry.	
S, SO_2, S_2O_3, SO_3, etc.	Weighing.	Precipitant $BaCl_2$ in hot solution containing a little free HCl.	$BaSO_4$	Same as $BaSO_4$.	Same as $BaSO_4$.	Same as $BaSO_4$.	Same as $BaSO_4$.	$BaSO_4$
Cl	Weighing.	Precipitant $AgNO_3$.	AgCl	Same as Ag.	Same as Ag.	Same as Ag.	Same as Ag.	AgCl.

Si and SiO_2	Weighing.	By evaporation of acid solution to dryness and heating at 115° to 120°C., or by evaporation of H_2SO_4 solutior to fumes of SO_3	xH_2O, SiO_2	Should contain HCl. If much HNO_3 is present, should be removed by adding HCl and boiling.	Boiling caustic fixed alkalies. By fusion with fixed alkalies (caustic or carbonate). Insoluble in H_2O and acids (HF excepted).	Insoluble sulphates, removed by digestion with conc. H_2SO_4. Also SnO_2, Sb_2O_4, and TiO_2. Sometimes Al_2O_3 and Fe_2O_3, in which case determine by loss.	Ignition after drying. When impurities are present is determined by loss on ignition with HF and H_2SO_4.	SiO_2
C, CO_2, etc.	Weighing.	Absorption with KOH, NaOH, or $Ca(OH)_2$ + NaOH.	Na_2CO_3, K_2CO_3 or Na_2CO_3 + $CaCO_3$.	....	....	H_2O and CO_2 from the atmosphere. Prevented by suitable absorption apparatus.	Absorption in weighed apparatus containing suitable absorbents.	CO_2
N	Weighing.	$PtCl_4$.	$(NH_4)_2PtCl_6$	Same as K_2PtCl_6.	Same as K_2PtCl_6.	Same as K_2PtCl_6.	Ignition to Pt. (See K_2PtCl_6).	Pt

Quantitative Precipitation of Metals by Electrolysis[1]

Solution	Au	Pt	Pb	Ag	Hg	Pd	Sb	Sn	Cu	Bi	Cd	Tl	Fe	Mn	Zn	Co	Ni	Se
Nitric or sulphuric	..	—	—	—	—	+(a)	..	..	—	—	—	+(b)	......	+(c)	—(d)	..	..	....
Double ammon. oxalate	..	..	—	—	..	......	..	—	—	—	—(e)	—	......	+(f)	—	—	—	....
Double ammon. sulphate	..	..	..	—	..	......	..	..	..	..	......	......	—(g)	+(h)	—	—	—	....
Double potass. cyanide	—	..	..	—	..	......	..	..	..	..	......	......	......	......	......	..	..	+ —(i)
Sulpho-salt	..	..	..	..	..	......	—	—	..	..	......	......	......	......	......	..	..	....
Glacial phosphoric acid after $(NH_4)_2CO_3$	..	..	..	..	..	......	..	—	—	—	......	......	—	+	—	—	—	....

[1] Kahn and Woodgate, "*Journ. Soc. Chem. Ind.*," Vol. VIII, p. 256.

— Precipitated on cathode as metal.

\+ Precipitated on anode.

(*a*) On anode as PbO_2.

(*b*) On anode as Tl_2O_3

(*c*) On anode as MnO_2.

(*d*) From alkaline or neutral solution.

(*e*) Potass. salt preferable.

(*f*) Incompletely. Completely from potass. salt.

(*g*) After adding $Na_3C_6H_5O_7$ and $H_3C_6H_5O_7$.

(*h*) Incompletely.

(*i*) Doctor Keller (private communication) called attention to the precipitation of selenium as metal at both cathode and anode. This seems to be the only case where this is true.

SECTION VI

ORE DRESSING

CRUSHING

Stamps, Chilean mills and rolls are used for coarse crushing; feed generally not over 2 in. and discharge screen about 35 to 40 mesh. The roll makes less fines in the product than either of the others. HARDINGE mill is a stage crusher; feed about ¾ in. product uniform fine sand with but little slime; HUNTINGTON mill, regrinding machine; best feed not over ¼ in. makes considerable slime. Tube mill is best and only logical fine grinding machine.

Abbé Tube Mill.—The original ABBÉ gear-driven mill was supported on a pair of riding rings. The distinguishing feature was a spiral of Archimedes through which the ore was fed and discharged. Tube mills now supported either on riding rings or trunnions. Early tendency was toward long mill of small diameter, 22 ft. by 3½ ft., now changing to 5 and 6 ft. diameter and 16 to 18 ft long. Grinding effected by flint pebbles fed into mill. (See Ball mill.)

Amalgamating Pan.—This is a flat-bottomed iron pan with an iron cone in the center, with high sides, nearly or quite vertical, and in it a horizontal, annular disk, called a muller, is revolved. Many authorities claim that this should not be used as a grinder, but only as an amalgamator. From 3 to 5 hp. is needed for amalgamating, and 5 to 10 hp. for grinding in a 5-ft. pan.

Arrastre.—A machine having horizontal surfaces grinding concentrically on a vertical shaft. In its original form it consists of a circular pavement from 6 to 20 ft. in diameter with a retaining wall around it and a step in the center. Upon the step stands a vertical revolving spindle from which extend horizontal arms, to which large boulders, called dragstones, are attached by chains.

Ball Mill.—Short tube mill (*q.v.*) of relatively large diameter in which grinding is done by steel balls instead of pebbles. Wet grinding with steel balls formerly considered unwise due to excessive steel consumption now coming into favor.

Blake Crusher.—Original crusher of jaw type. Rock is crushed between two jaws set at an angle to each other, one fixed and the other swinging from top suspension rod. Motion imparted to lower end of crushing jaw by toggle joint operated by eccentric. (See also DODGE crusher.)

Bryan Mill.—A form of Chilean mill using three rollers instead of two. The wear seems a little more even in this type of mill than in the HUNTINGTON or the regular Chilean.

Chilean Mill (Edge Runner).—These mills have vertical rollers running in a circular enclosure with a stone or iron base or die. They are of two classes: (*a*) those in which the rollers gyrate around a central axis, rolling upon the die as they go (the true Chile mill; (*b*) those in which the enclosure or pan revolves, and the rollers, placed on a fixed axis, are in turn revolved by the pan. It was formerly used as a coarse grinder, but is now used as a fine.

Dodge Crusher.—Similar to Blake crusher (*q.v.*) except movable jaw is hinged at bottom. Therefore discharge opening is fixed giving a more uniform product than Blake with its discharge opening varying every stroke, but this decreases capacity.

Dodge Pulverizer.—A hexagonal barrel revolving on a horizontal axis, containing perforated die plates and screens. Pulverizing is done by steel balls inside barrel.

Edge Runner.—See Chilean mill.

Fuller-Lehigh Pulverizing Mill.—For coal dust pulverizing only. Used by the Pennsylvania Steel Co., at Lebanon, Penn.

Gardner Crusher.—A swing-hammer crusher, the hammers being flat U-shaped pieces hung from trunnions between two disks keyed to a shaft. When revolved, centrifugal force throws hammer out against feed and heavy anvil inside crusher housing.

Griffin Roller Mill.—A centrifugal mill, like the Huntington except there is one roller only (see "Huntington"). The mill is consequently unbalanced and requires a very solid foundation.

Gyratory Crusher.—Consists of a vertical spindle the foot of which is mounted in an eccentric bearing. The top carries a conical crushing head revolving eccentrically in a conical maw. There are three types of gyratory: those which have the greatest movement on the smallest lump; those that have equal movement for all lumps; those that have greatest movement on largest lump.

Hardinge Mill.—This is a tube mill made with two conical sections connected by a central very short cylinder. The cone at the feed end is very short so that the large pebbles settle and grind at the large end where the feed is coarse.

Huntington Mill.—This operates by the centrifugal force of steel rollers revolving against the inner surface of a heavy horizontal steel ring or die. The rollers are suspended upon rods from horizontal arms by short trunnions allowing a swing of the rod and roller in a direction radial from the central vertical shaft.

Kent Roller Mill.—This consists of a revolving steel ring with three rolls pressing against its inner face. The rolls are supported on springs, and the rings support the roll, so that there is some freedom of motion. The material to be crushed is held against the ring by centrifugal force.

Kinkead Mill.—This is a pan mill with a convex conical bottom on which a muller, having two surfaces of different

inclinations, grinds. The machine acts on the gyratory principle as regards crushing between the surfaces.

Jeffrey Swing-hammer Crusher.—In an iron casing a shaft revolves carrying swinging arms having a free arc movement of 120°. The rotation of the driving shaft causes the arms to swing out and strike the coal or other brittle material, which, when sufficiently fine, passes through the grated bottom.

Krupp Ball Mill.—This is the classic ball mill. Grinding was done by chilled-iron or steel balls of various sizes which ground against each other and the die ring, composed of five perforated spiral plates, each of which lapped the next. This formed steps which gave the balls a drop from one plate to the next, and in addition, gave a space through which oversize was returned. Outside the die-plate is a coarse perforated screen to take the chief wear, while outside that come fine gauze screens. The fines discharge through these into the housing inside which the screens revolve and which has a hopper bottom.

Lane Mill.—A slow-speed roller mill of the Chilean type. A horizontal spider carrying six rollers revolves slowly in pan 10 ft. or more in diameter making about 8 r.p.m. Advantages: great crushing weight, low power, decreased wear due to slow speed.

Marathon Mill.—A form of tube mill used in the cement industry, in which the pulverizing is done by long pieces of hardened steel shafting.

Marcy Mill.—A ball mill in which a vertical diaphragm is placed about 1 ft. from the discharge end. Between this perforated diaphragm and the end of the tube there are arranged screens for sizing the material, oversize being returned for further grinding while undersize is discharged.

Nissen Stamps.—This is a gravity stamp with an individual circular mortar for each stamp.

Rolls.—Two cylinders, with faces much less than the diameters, revolving toward each other, drawing the material in between the crushing peripheries. One roll at least usually runs in fixed bearings, the other may or may not run in movable bearings held by springs.

Roll Jaw Crusher.—Same general type as Blake and Dodge (*q.v.*), but moving jaw has rolling instead of oscillating motion.

Stamp Battery.—In effect a heavy iron pestle working mechanically in a huge iron mortar. Generally grouped in units of five per mortar. Stamps vary up to 2000 lb. in weight, dropping 6 to 8 in. over 100 times per minute.

Sturtevant Balanced Rolls.—All four boxes are movable and held in position by springs. The idea is to divide the thrust whenever the springs yield and, by dividing by two the distance the roll must move, to reduce internal stresses.

Sturtevant Grinder.—A disk grinder in which one disk is stationary and the other rotates. The stationary disk is moved out of center from time to time, so that any groove which forms can be ground out.

Sturtevant Roll Jaw Crusher.—A crusher in which the motion of the upper part of the jaws is very like that of the DODGE crusher, while the lower parts of the jaws, two cylindrical surfaces of varying radii, grind the ore between them.

Sturtevant Ring-roll Crusher.—Works as does the KENT roller mill, which see.

Symon's Disk Crusher.—A mill in which the crushing is done between two cup-shaped plates which revolve on shafts set at a small angle to each other. These disks revolve with the same speed in the same direction and are so set as to be widest apart at the bottoms. Feed is from the center and the material is gradually crushed as it nears the edge, and is then thrown out by centrifugal force.

Williams Hinged-hammer Crusher.—A machine similar to the JEFFREY machine. There is a rotating central shaft carrying a number of hinged hammers, which fly out from centrifugal force, crushing the feed against the casing.

Crushing with Jaw Crushers

The jaw crusher is probably still the most popular method of reducing the size of ore. A table is given below of what has actually been done with jaw crushers, taken from RICHARD'S "Ore Dressing," but the ordinary table of manufacturer's figures on crusher outputs, etc., is omitted for reasons given in part of the general discussion by MILTON H. HELLER in the *Engineering and Mining Journal*, Feb. 27, 1915.

When it is observed that the material fed to crushers is for the most part wet, as it comes from the mine, or dampened to reduce the dust, it is apparent the water exerts a lubricating action, which is further augmented should any clayey material be present. This condition might at any time bring the coefficient of friction down to 0.2. Again using RICHARD'S formulas, the angle of nip would have to be 11° or under before a bite would occur.

The great variety of shapes and sizes fed to a crusher, as compared with the rather uniform product to the rolls, would indicate that whereas a roll operating with an angle of nip of 16° is just on the danger point, a crusher so operated would have exceeded it. From this reasoning it would appear correct that the angles between the jaws of a crusher should not exceed 12° to work near its utmost capacity.

By referring to the accompanying table, it is readily seen what degree of reduction under present standard measurements of construction will bring the jaw angle about this limit:

DEGREE OF REDUCTION AND JAW ANGLE, BLAKE CRUSHERS

Size of crusher, in.	Actual width opening, in.	Length vertical jaw, in.	Set to crush to, in.	Angle between jaws
4 × 7	4	12	½	15° 50′
			1	13° 45′
			1½	11° 50′
			2	9° 25′
7 × 10	6¼	17½	1	16° 30′
			1½	15° 0′
			2	13° 15′
			3	10° 30′
9 × 15	8¼	24	1½	15° 25′
			2½	13° 10′
			3	12° 0′
			4	9° 30′
10 × 20	8½	26	1½	14° 40′
			3	11° 30′
			4	9° 40′
13 × 24	11½	33	1½	16° 30′
			3	14° 15′
			4	12° 30′
			5	11° 0′
15 × 24	13⅓	33	1½	22° 30′
			2	21° 45′
			3	20° 30′
			4	18° 30′
			5	17° 15′
			6	15° 20′
			7	13° 30′

The manufacturers, no doubt, have exceeded this angle, because it gave them the mouth-size that was sought, for the least cost. The direction that has been taken to increase crusher capacity has been to make a wider jaw. It would have been better if the jaw angle had been made smaller, and the additional iron put into the height of the jaw, rather than the width. The second point, the breaking character of the rock, is important, but is a character outside of our control.

It is readily admitted that a decrease in the size of the discharge opening will reduce the capacity. This amount of reduction is, however, greatly underestimated. Extending the principle given by RICHARDS in Vol. I, p. 35, of his "Ore Dressing," we may argue that in a 15 × 24-in. breaker, if one 15-in. cube reports at the mouth in 125 3-in. cubes, then the capacity at mouth is 125 times that at the throat when breaking to 3 in. If, now, the crushing be reduced to 1½ in., there would be 1000 cubes produced, and the capacity would be 1000 times greater at the mouth than at the throat. The capacity,

then, in the second case would be theoretically but one-eighth of that in the first case.

With the smaller opening there would be a proportionally larger amount of material that would have to be worked on, as with a smaller opening the probability of more stuff being smaller than that opening would be increased. This would have an added effect in reducing the output. As an illustration of how much this capacity reduction is underestimated, apply the principles stated to the catalog capacity of a 15 × 24-crusher:

Comparison of Capacities

	Approximate capacity for 24 hours			
Break to	3 in.	2½ in.	2 in.	
Tons	600	480	420	......

Theoretical

Break to	3 in.	2½ in.	2 in.	1½ in.
Tons	600	347	177	75

An analysis of a catalog table will show the error of basing estimates upon the figures given.

Approximate Capacity in Tons per Day of 10 Hours

Size	Tons	In.	Tons	In.	Tons	In.	Tons	In.
I—7×10	50	2	40	1½	25	1	15	¾
II—9×15	120	2½	100	2	80	1½	60	1
III—11×18	200	3	175	2½	150	2	100	1½

In case I it is seen that a change from 2-in. to 1-in. product gives 0.5 the output; from 1½ to ¾ in., 0.37 the output. In case II, a change from 2 in. to 1 in. gives 0.62 of the output. In case III, a change from 3 in. to 1½ in. gives five-tenths (0.5) the output.

There is no consistency in the table, the intermediate size showing less cut than the one larger and the one smaller. The table is in all probability no more than a guess.

Crushing with Blake Type of Breakers

Abbreviations.—C. = solid cast-iron frame; Cap. = capacity; Est. = estimated; gris. = grizzly; HP. = horsepower; h. = hours; In. = inches; L. = lever pattern; Min. = minute; P. = Pitman pattern; p. = per; picked = poor residue left after picking; Rev. = revolutions; S. = sectional bolted frame.

Breaker No.	Pattern	No. used	Mouth size, in.	Rev. per min.	Feed size	Crushed to, in.	Actual cap. per 24 h. per breaker tons	Est. cap. per 24 hr., tons	Run	Repairs per year exclusive of wearing parts	Est. HP.
1	......	1	6×8	450	Mine ore..................	....	50	125	Dry	....	....
1	P. C.	1	10×13	360	Mine ore..................	¾	100–120	300	Wet	$100	....
1	L. C.	1	6×8	500	Mine ore over 1½ in. griz...	1	....	....	....	....	....
1	P. C.	1	10×16	250	Mine ore over 2 in. griz.....	2	50	150	Dry	(c)	20
1	P. C.	1	6×10	350	Mine ore..................	1	80	200	Wet	....	....
1	L. C.	1	6×9	125	Mine ore..................	¾	37½–40	112–120	Wet	None	4
1	L. C.	1	6×9	400	Mine ore picked...........	⅝	....	....	....	....	....
1	P. C.	1	7×10	320	Mine ore..................	1½	95	....	....	....	....
1	P. C.	1	9×11	....	Mine ore picked...........	1½	....	....	....	....	....
1	P. S.	1	8×10	300	Mine ore over 1¼ in. griz...	1½	100	200	Dry	....	....
1	P. C.	1	7×10	250	Mine ore..................	1	40–50	....	Wet	....	....
1	P. C.	1	9×15	....	Mine ore..................	1½	100	....	....	....	....
1	L. C.	1	9×15	214	Mine ore..................	½	109	140	Wet	$155	....
1	L. C.	10	9×15	180	Mine ore..................	1½	90	125	Dry	$ 90	7
1	P. C.	2	9×15	250	Mine ore picked...........	1½	80	150	Wet	$ 20	....
2	P. C.	1	7×12	250	Mine ore over 1¼ in. griz...	1½	100	....	Dry	....	7
1	P. C.	2	8×10	400	Mine ore..................	1 1/16	350	....	....	....	....
(a)	P. C.	1	9×15	340	Selected shipping ore.......	2½	....	....	Dry	....	10
(b)	P. C.	1	9×15	340	Mine ore picked, over 1¼ in. griz.	2½	....	....	Dry	....	25

CRUSHING WITH BLAKE TYPE OF BREAKERS. *Continued*

Breaker No.	Pattern	No. used	Mouth size, in.	Rev. per min.	Feed size	Crushed to, in.	Actual cap. per 24 h. per breaker tons	Est. cap. per 24 h., tons	Run	Repairs per year exclusive of wearing parts	Est. HP.
1	P. C.	1	7×10	350	Mine ore picked...........	1½	200	230	Wet	....	7
1	P. C.	2	9×15	280	Mine ore over 1½ in. griz...	1½	250	350	Dry	None	12
1	P. C.	1	7×11	224	Mine ore.................	.....	75	....	Wet	....	....
1	P. C.	1	7×12	....	Mine ore over 1½ in. griz...	.....	60	....	Dry	....	....
1	P. C.	1	9×15	....	Mine ore.................	.....	....	....	.....	....	....
1	P. C.	2	10×20	300	Mine ore over 1 in. griz.....	1½	300	....	Dry	....	....
2	P. C.	4	7×10	300	(*k*) On No. 1 trommel 1½ in..	.....	....	....	.....	....	....
1	P. C.	2	9×15	350	Mine ore.................	2½	250	....	Wet	....	....
2	P. C.	2	4×10	250	(*k*) on No. I trommel 2⅛ in..	1	....	....	Wet	....	....
1	P. C.	2	9×15	275	Mine ore.................	2	300	400	Wet	None	....
2	P. C.	4	7×10	275	(*k*) On No. 1 trommel, 20 mm	1	30	100	Wet	None	....
1	P. C.	1	9×15	250	Mine Ore.................	2	300	400	Dry	Small	....
2	P. C.	1	7×10	250	(*k*) On No. 1 trommel, ⅞ in.	1	....	100	Dry	Small	....
1	P. C.	11	24×36	190	Mine ore, over 3½-in. griz...	12	480	....	Dry	....	....
2	P. S.	11	17×24	200	(*k*) On No. 2 grizzly 3½ in..	3½	....	....	Dry	....	....
1	P. C.	2	14×22	84	Mine ore over 4 in. griz.....	4	....	....	Dry	....	....
2	P. C.	2	13×20	140	Mine ore over 4 in. griz.....	4	....	....	Dry	....	....
1	P. C.	3	18×24	84	Mass copper rock (*m*)......	5	....	....	Dry	(*e*)	....
2	L. C.	6	9×15	129	From No. 1 breaker.........	2¾	....	....	Dry	....	....
3	P. C.	6	13×20	103	Copper rock (*m*)...........	3	....	....	Dry	....	....
1	P. C.	4	18×24	132	Mine ore over 4 in. griz.....	4	....	....	Dry	....	....
1	L.	6	8×15	216	Mine ore over 4 in. griz.....	4	....	....	Dry	....	....

1	P. C.	1	10×15	250	Mine ore	1½	50	130	Dry	(p)	7
1	P. C.	3	9×15	200	Mine ore over 2 in. griz.	1½	15	75	Wet	(f)	14
1	L. C.	2	9×14	200	Mine ore over 3 in. griz.	2	20	....	Dry	....	....
1	P. S.	3	8×12	240	Mine ore over 1½ in. griz.	1½	24	50	Dry	(g)	15
1	P. C.	1	9×12	250	Mine ore over griz.	1½	15	....	Dry	....	....
1	P. C.	1	9×12	300	Mine ore over 1⅜ in. griz.	1	116	200	Dry	$30	7
1	P. S.	1	10×16	200	Mine ore over 2 in. griz.	2	110	....	Dry	....	....
1	P. C.	3	9×15	250	Mine ore over 1½ in. griz.	1½	43	....	Dry	(r)	10
1	....	1	9×16	....	Mine ore over 2 in. griz.	1½	100	....	Dry	....	....
1	P. S.	2	12×16	195	Mine ore over 2 in. griz.	1½	75	....	Dry	....	....
1	P. S.	2	12×16	195	Mine ore over 2 in. griz.	1½	75	....	Dry	....	....
1	P. C.	2	9×15	250	Mine ore over 1½ in. griz.	1½	43	....	Dry	(r)	10
2	P. C.	2	9×15	200	(n) On trommel, 1 in.	1½	Under 50	100	Wet	(h)	12
1	P. C.	1	7×9	220	Mine ore	1½	....	....	Wet	....	....
1	P. C.	1	7×10	220	Mine ore	1	75	....	....	....	....
(d)	P. C.	1	8×12	252	Mine ore	1½	....	....	Dry	....	....
1	P. C.	1	9×15	250	Mine ore	1½	125	....	Dry	....	....
1	P. C.	1	7×12	....	....	1½	75	....	Wet	....	....
1	P. C.	1	12×24	270	Mine ore	2	125	300	Dry	None	15
2	P. C.	1	12×24	270	Product of No. 1 breaker	1	125	300	Dry	....	....
3	P. C.	2	9×17	270	Product of No. 2 breaker	¾	62	150	Dry	....	....
1	P. C.	1	9×15	200	Mine ore	1½	....	....	Dry	....	....
1	P. C.	1	15×30	270	Mine ore over 1½ in. griz.	4	....	....	Dry	....	....
2	P. C.	1	(q)	276	(j)	¾	....	....	Dry	....	....
1	....	1	9×15	....	Mine ore	1½	80	200	Wet	....	....

(a) For shipping ore. (b) For concentrating ore. (c) Rubber springs, cost $3.50 each, last 2–4 weeks. (d) Sampler. (e) Twelve days a year. (f) Less than $20 per breaker per year. (g) Very hard ore, so that pitman sometimes breaks. (h) BABBITT for bearings. Jaw springs. (j) Product of No. 1 breaker, picked; also stuff through 1½-in. gris., picked. (k) Through No. 1 breaker. (m) Over 2¾-in. gris. and from fall hammer. (n) Through COMET breaker, 3 in. (p) BABBITT once in 2 years, nothing else. (q) This is a Duplex breaker with each mouth 6 × 20 in. (r) BABBITT bearings annually, cost $10.

Estimated Cost of Crushing by Jaw Crusher[1]

Size of mouth in inches	4 × 10	7 × 10	9 × 15	10 × 20	13 × 30
Tons crushed in 24 hours	84	120	192	300	540
Horsepower	5	8	12	20	30
Cost of breaker	$275	$500	$750	$1050	$2250
Cost, cents per ton, oil	0.021	0.021	0.021	0.021	0.021
Cost, cents per ton, interest and depreciation	0.106	0.135	0.127	0.114	0.135
Cost, cents per ton, power	0.773	0.865	0.811	0.865	0.721
Cost, cents per ton, labor	4.762	3.333	2.083	1.333	0.741
Cost, cents per ton, wear	0.815	0.815	0.815	0.815	0.815
Cost, cents per ton, repairs	0.462	0.462	0.462	0.462	0.462
Total cost, cents per ton	$6.939	$5.631	$4.319	$3.610	$2.895

Estimated Cost of Crushing by Spindle Breakers[2]

Number of breaker	0	2	4	6	8
Size of mouth in inches	4 × 30	6 × 42	8 × 54	11 × 72	18 × 126
Tons crushed in 24 hours	72	216	540	1080	3000
Horsepower	3	9	22	45	125
Cost of breaker	$375	$760	$1800	$3300	$7000
Cost, cents per ton for oil	0.021	0.021	0.021	0.021	0.021
Cost, cents per ton interest and depreciation	0.169	0.114	0.108	0.099	0.076
Cost, cents per ton, power	0.541	0.541	0.541	0.541	0.541
Cost, cents per ton, labor	5.556	1.852	0.741	0.370	0.133
Cost, cents per ton, wear	0.971	0.971	0.971	0.971	0.971
Cost, cents per ton, repairs	0.308	0.308	0.308	0.308	0.308
Total cost in cents per ton	$7.556	$3.807	$2.678	$2.310	$2.050

Per Cent. of Voids in Crushed Limestone[3]

Screen opening, inches	Per cent. of voids	
	By water displacement	From specific gravity
3/8	40.9	46.8
3/8	39.6	46.1
1/2	42.2	47.1
3/4	43.0	45.6
1 1/4 to 3/8	45.7	44.7
2 to 1/2	47.9	46.2
2 to 3/4	46.6	46.6
2 1/4 to 3/8	44.3	42.9
2 1/4 to 1 1/4	46.2	43.4
3 to 2	46.1	45.1
3 to 2	47.5	46.1

[1] R. H. Richards, "Ore Dressing," Vol. I.
[2] R. H. Richards, "Ore Dressing," Vol. I.
[3] Richards, "Ore Dressing," Vol. IV.

An ordinary mine wedge, 8 in. long by 4 in. wide by 2 in. thick at the large end, when caught in 9×15-in. breakers, takes about as long to work through as does a ton of ore. Moral—remove the wood first.

So far as known, up to the date of writing, July 16, 1915, the largest jaw crusher is one made by the Traylor Engineering and Manufacturing Co., a 66 × 84-in. jaw crusher for the Rockland Lake quarry of the Conklin & Foss Co. on the west bank of the Hudson River just north of Nyack. This crusher, described in detail in the *Engineering and Mining Journal* of Mar. 27, 1915, is slightly larger than the jaw crushers the Traylor company has previously supplied. The crusher weighs about 520,000 lb. and is approximately 18 ft. high, 26 ft. long and 20 ft. wide. The driving pulley is 12 ft. in diameter and a 350-hp. Westinghouse MS motor will be used to drive the crusher. Fourteen railroad cars were required to transport the crusher from the shops to the quarry, where blockholing and bulldozing will be practically eliminated by the unit.

Symon's Disk Crushers[1]

For the work of secondary breaking from a 3- to 5-in. size, to approximately 1½ in., the Symons disk crusher is now being largely used, and has been adopted by the larger mining companies such as Phelps, Dodge & Co., the Guggenheim companies, the Anaconda Copper Co., and the Inspiration Copper Co. Records of the Detroit Copper Co. at Morenci, Ariz., give a life of 170,000 tons for one set of manganese-steel disks, which are the main wearing parts, and cost about $300. The Federal Lead Co., at Flat River Mo., obtained the low figure of 0.2 ct. per ton for wear over a period of a year.

A test of capacity, power and size of the product of a 48-in. disk crusher was made by David Gilmour, chief engineer for the Guggenheim Exploration Co., with a view to determining the advisability of using it instead of 72 × 20-in. rolls, and as a result the disk crusher was adopted for the Chile Copper Co., at Chuquicamata, Chile. One of the tests was as shown herewith:

Test of Disk Crusher

Feed, 20 per cent. 4 to 6 in., 50 per cent. 2 to 4 in., 25 per cent. 1 to 1½ in.

Crusher opening, 1¼ in.

Product, 78 per cent. ½ to 1½ in., 22 per cent. ½ in. and smaller.

Capacity, 100 tons per hour.

Power, 29 to 47.9 hp.

It will be noted that the rated capacity for this crusher with 1½-in. product is 60 to 80 tons; the power from 50 to 65 hp., so that the catalog ratings are conservative.

In a more practical way the advantages of the disk crusher can be shown by a comparison of costs, which are available for

[1] Julius I. Wile, "Tendency of American Milling Machinery Practice," "*Eng. and Min. Journ.*," Apr. 17, 1915.

1000-ton units for secondary breaking from $3\frac{1}{2}$ into $1\frac{1}{2}$ in. The accompanying estimate is based on the cost of power and repairs only, with 8 hr. crushing and power taken at the low figure of \$50 per hp. per year, the average yearly tonnage being 350,000 tons. The estimate is given for both class A and class B ores, and comparison is made between gyratories, rolls and disk breakers.

Crusher Action on Various Ores—Class A

	Two No. 5 gyratories, 50 hp. (25 hp. each)	72 × 16-in. rolls, 60 hp.	48-in. disk, 40 hp.
Power	0.24 cts.	0.29 cts.	0.2 cts.
Repairs	0.65 cts.	0.50 cts.	0.2 cts.
Total	0.89 cts.	0.79 cts.	0.4 cts.

Class B

	Two No. 6 gyratories, 66 hp. (33 hp. each)	72 × 20-in. rolls, 80 hp.	48-in. disk, 50 hp.
Power	0.32cts.	0.39 cts.	0.25 cts.
Repairs	1.30cts.	1.00 cts.	0.40 cts.
Total	1.62cts.	1.39 cts.	0.65 cts.

Crushing with Rolls[1]

According to Philip Argall the most successful dry crusher is the belted roll. They do their best work on $1\frac{1}{2}$- to 2-in. cubes. In wet crushing they give good results down to 20-mesh and fair down to 40-mesh. According to Mr. Argall the following formulas give the proper roll speed: Let P = peripheral speed in feet per minute; D = diameter of rolls in inches; N = the number of revolutions per minute; S = size in inches of maximum ore cube fed; S_n = size in inches of maximum cube fed for a given diameter of roll; then

$$100 \times \frac{\log \frac{16}{s}}{\log 2} = P;\ 0.0476 \times D = S_n;\ \frac{382}{D} \times \frac{\log \left(\frac{16}{s}\right)}{\log 2} = N.$$

The angle of nip for a given particle is the angle between the tangents drawn to the rolls at the points where the particle touches. The most favorable angle is 32°.

The largest particle which can be fed to a set of rolls, according to Haton de la Goupillière is: $\frac{r}{R} > 18 - 19m$; where r = radius of roll, R = radius of largest particle in the feed, and

[1] R. H. Richards, "Ore Dressing," Vol. III.

m = ratio between diameter of the largest grain in crushed product and that of the largest grain in the feed.

The theoretical capacity of the rolls is: $\frac{60PWS}{1728} = C$; where P = peripheral speed in inches per minute, W = width of roll face in inches, S = space between the rolls in inches, and C = capacity in cubic feet per hour.

Size of Feed to Give a 32° Angle of Nip on Different Rolls

Diameter of rolls in inches	Space between the rolls in inches						
	3/4	5/8	1/2	3/8	1/4	1/8	0
36	2.23	2.10	1.96	1.84	1.71	1.57	1.45
30	1.99	1.86	1.73	1.60	1.47	1.34	1.21
26	1.83	1.70	1.56	1.44	1.31	1.17	1.05
24	1.74	1.61	1.48	1.36	1.22	1.10	0.96
20	1.58	1.46	1.32	1.20	1.06	0.94	0.80
16	1.42	1.29	1.16	1.03	0.90	0.77	0.64
9	1.14	1.01	0.88	0.75	0.62	0.49	0.36

Size of Feed to Give a 32° Angle of Nip on Different Rolls

Diameter of rolls in inches	Size of feed to rolls in inches					
	1 1/2	1 1/4	1	3/4	1/2	1/4
	Space between rolls (a)					
36	0.46	......	......	......	......	......
30	0.280	0.038	......	......	......	......
26	0.432	0.191	......	......	......	......
24	0.512	0.270	0.031	......	......	......
20	0.666	0.424	0.185	......	......	......
16	0.822	0.580	0.340	0.101	......	......
9	1.193	0.851	0.613	0.372	0.132	......

(a) Where blank spaces are left the angle of nip is under 32° with the rolls set close together.

Width of Rolls.—According to Richards the following are the chief considerations. Wide rolls of the same speed have more surface and hence greater capacity. But as width and capacity increase so do the stresses to be met, and consequently the cost of the machine increases. On the other hand, narrow rolls are much easier to keep true, and by running them faster, provided the speed does not exceed the limits for good work, the capacity lost by narrowing can be regained, the stresses are less, and first cost, weight and friction are reduced.

A table of results of roll crushing, taken from Richards, follows:

General Table of Roll Data

Abbreviations.—Bl. = Blake breaker; cap. = capacity; est. = estimated; G. = Gates breaker; gr. = grizzly; h = hours; in. = inches; j.m. = jig middlings; L. = Lowry breaker; mag. = magnetic; max. = maximum; mid. = middlings; ov. = oversize; s. = sectional; th. = through; No. = number; tr. = trommel.

Roll No.	Feed	Product to	Space between rolls, in.	Diameter, in.	Face width, in.	Revolutions per minute	Est. horse-power re-quired	Cap. per 24 h. tons (a) Actual	Cap. per 24 h. tons (a) Max.	Class (r)
1	From Bl.	Hand jig.	¾	12	14	100	.....	50	130	I
1	Th. Bl., ¾ in., on No. 1 tr., ½ in.	No. 1 tr., ½ in.	Close	22	14	22	.....	300	....	II
2	J. m. th. ½ in.	No. 1 tr., ½ in.	Close	18	14	22	.....	.....	....	IV
1	Th. Bl., 1 in., on No. 1 tr., 2 mesh.	No. 1 tr., 2 mesh.	Close	26	12	20	.....	.....	....	II
1	Th. Bl., 1 in.	No. 1 tr., 0.487 in.	¾	22	14	42	.....	40	....	I
2	J.m., 1 to 0.09 in.	No. 1 tr., 0.487 in.	Close	22	14	.....	.....	.....	....	IV
1	(b)	No. 1 tr., 20, 10, 2 mm. (S.)	Close	18	14	75	.....	60	70	I, IV
1	(c)	No. 1 tr., 15 mm.	Close	20	14	90	.....	45	50	II, IV
1	Th. Bl., 1½ in., on No. 1 tr., 0.141 in.	No. 2 tr., 0.083 in.	¼	36	14	(d)	.....	100	250	II
1	Th. Bl.	No. 1 tr., 3 mesh.	....	.....	.....	.....	.....	.....	....	I
2	Ov. No. 1 tr., 3 mesh	No. 2 tr., 5 mesh.	....	.....	.....	.....	.....	.....	....	III
1	(e)	No. 2 tr., 0.252 in.	½	24	12	92(f)	.....	100	....	II
2	Ov. of No. 2 tr., 0.252 in.	No. 2 tr., 0.252 in.	¼	24	12	100	.....	60–80	....	III
3	J.m., 0.252 to 0.060 in.	No. 6 tr., 0.060 in.	Close	16	9	120	.....	.....	....	IV
1	Th. Bl., 1 in.	No. 1 tr., 0.177 in.	¼	27	14	80	10	(g)	....	I
2	Ov. No. 1 tr., 0.177 in.	No. 1 tr., 0.177 in.	Close	24	14	80	10	25	....	III
1	Th. Krom breaker, 1 in.	No. 1 tr., 12 mm.	0.4	30	16	28(h)	20	.....	....	I
2	(i)	No. 1 tr., 12 mm.	Close	30	16	40	20	.....	....	III, IV
1	Th. Blake., 1½ in.	No. 1 tr., 7 mm.	....	27	14	.....	.....	100	....	I
2	(j)	No. 1 tr., 7 mm.	Close	27	14	.....	.....	100	....	III, IV
1	Th. Bl., ½ in., on No. 1 tr., 10 mm.	No. 2 tr., 7 mm.	⅓ to ½	28½	12	24	.....	75	100	II
2	Ov. No. 2 tr., 7 mm.; J.m., 10 to 0 mm.	No. 2 tr., 7 mm.	¼ to 5/16	30	12	24	.....	142	190	III, IV
1	Th. Bl., 1½ in.; Ov. No. 1tr., 6 mm.	No. 1 tr., 6 mm.	Close	30	14	8½	8	105	125	I

2	Jig skimmings, 6 mm. to 0.	Jigs.	Close	30	14	60	5	50	55	IV
1, 2	From Dodge breaker, 1 in.	No. 2 tr., 0.224 in.	⅛ to 3/16	36	16	42	9(*k*)	100	150	I
3	Ov. No. 2 tr., 0.224 in.	No. 2 tr., 0.224 in.	Close	36	16	50	.....	200	....	III
1	Th. Bl., 1½ in., on No. 1 tr., 1½ in.	No. 2 tr., ⅝ in.	½	36	14	42	.....	150	....	II
2	Jig tailings, ½ to 21/64 in.	No. 9 tr., 21/64 in.	⅛	36	14	100	.....	.....	....	IV
1	(1)	No. 2 tr., 16 mm.	⅛	26	14	40	9	96	100	II, IV
2	J.m., 16 to 5 mm.; ov. No. 8 tr., 3½ mm.	No. 8 tr., 3½ mm.	Close	30	16	35	5	24	100	IV
1	Th. Bl., 17 mm.	No. 1 tr., 8 mm.	½	21	12	45	.....	.....	....	I
2	Ov. No. 1 tr., 8 mm.	No. 1 tr., 8 mm.	¼	21	16	40	.....	.....	....	III
3	Th. No. 1 tr., 8 mm., on No. 2 tr., 6 mm.	No. 2 tr., 6 mm.	Close	21	16	.....	.....	.....	....	II
1	Th. gr., 1¼ in.; th. G. or Bl., 2½ in.	No. 1 tr., 25, 15, 10 mm. (S.)	½	36	14	40	10	275	....	I
2	Th. No. 1 rolls on No. 1 tr., 25 mm.	No. 1 tr., 25, 15, 10 mm. (S.)	½	24	14	26	6	65	....	III
3	J.m., 25 to 7 mm.	No. 1 tr., 25, 15, 10 mm. (S.)	Close	30	16	30	10	250	....	IV
4	J.m., 7 to 0 mm.; ov. No. 3 tr., 5 mm.	No. 3 tr., 5, 2½ mm. (S.)	Close	24	14	35	4	30	....	IV
1	Th. Bl., 1½ in.	No. 1 tr., 18, 15, 9 mm. (S.)	½	36	18	40	10	200	....	I
2	J.m., 1½ in. to 4 mm.	No. 1 tr., 18, 15, 9 mm. (S.)	¼	24	12	36	7	.....	....	IV
3	J.m., 4 mm. to 0; j.m., 2½ mm. to 0.	No. 3 tr., 2½ mm.	Close	24	12	.....	7	.....	....	IV
1	Th. Bl., 1½ in.; th. gr., 1½ in.	No. 1 tr., 12, 8 mm. (S.)	⅛	31	16	28	8	600	700	I
2	J.m., 1½ in. to 8 mm.	No. 4 tr., 5, 2 mm. (S.)	Close	36	14	55	9	350	450	IV
3	J.m., 8 to 5 mm.	No. 4 tr., 5, 2 mm. (S.)	Close	30	14	60	4	150	300	IV
4	J.m., 5 to 2 mm.	No. 4 tr., 5, 2 mm. (S.)	Close	30	14	60	4	150	300	IV
1	Th. Bl. 1 in., on No. 1 tr., 0.5 in.	No. 1 tr., 0.5, 0.31 in. (S.)	....	30	16	24½	.....	.....	....	II
2	J.m., 0.5 in. to 0.	No. 2 tr., 0.2, 0.13 in. (S.)	Close	20	10	42	.....	.....	....	IV
1	Th. gr., 1½ in., th. G., 1½ in.	No. 1 tr., 15 mm.	....	30	14	48	.....	300	....	I
2	Ov. No. 1 tr., 15 mm.; j.m., 15 to 11 mm.	No. 1 tr., 15 mm.	....	30	14	.....	.....	.....	....	III, IV
3	J.m., 11 to 3 mm.	No. 5 tr., 3 mm.	....	30	14	.....	.....	.....	....	IV
1	Th. gr., 1 in.; th. G., 1 in.	No. 1 tr., 16 mm.	½	26	15	62	10	300	....	I
2	(*m*)	No. 5 tr., 2½ mm.	Close	26	15	.....	15	.....	....	IV
1	Th. Bl.	No. 1 tr., 0.5 in.	....	24	14	.....	.....	.....	....	I
2	Ov. No. 1 tr., 0.5 in.; j.m., 0.5 to 0.31 in.	No. 1 tr., 0.5 in.	....	20	10	.....	.....	.....	....	III, IV

GENERAL TABLE OF ROLL DATA—*Continued*

Roll No.	Feed	Product to	Space between rolls, in.	Diameter, in.	Face width, in.	Revolutions per minute	Est. horse-power re-quired	Cap. per 14 h. tons (a) Actual	Cap. per 14 h. tons (a) Max.	Class (r)
3	J.m., 0.31 in. to 0	No. 3 tr., 0.2 in.	....	20	10	.....	.....	.....	....	IV
1	Th. G., 1½ in.; Ov. No. 1 tr., 25 mm.	No. 1 tr., 25 mm.	¾	26	15	40	.....	.....	....	II
2	J.m., 25 to 20 mm.	No. 1 tr., 25 mm.	½	26	15	47	.....	.....	....	IV
3	J.m., 20 to 3 mm.	No. 1 tr., 25 mm.	¼	20	12	37	.....	.....	....	IV
4	J.m., 10 to 3 mm.; ov. No. 7 tr., 7 mm.	No. 7 tr., 7, 3 mm. (S.)	1/16	42	12	42	.....	.....	....	IV
1	J.m., 1½ to ⅞ in.	No. 2 tr., ⅞ in.	½	26	15	60	.....	.....	....	IV
2	J.m., ⅞ to ⅜ in.	No. 2 tr., ⅞ in.	¼	26	15	60	.....	.....	....	IV
3	(n)	No. 6 tr., 2½ mm.	Close	26	15	60	.....	.....	....	IV
1	(o)	No. 2 tr., 1½ in., 15 mm. (S.)	3/16	30	16	38	.....	.....	....	IV
2	Jig tailings, 15 to 8½ mm.	No. 2 tr., 1½ in., 15 mm. (S.)	Close	26	15	40	.....	.....	....	IV
1, 3	From No. 2 Bl., 1 in.	No. 1 tr., 20 mm.	⅛	30	16	31	.....	50	75	I
2	J.m., 20 to 7 mm.	No. 1 tr., 20 mm.	1/16	30	16	31	.....	75	75	IV
4	J.m., 7 to 3 mm.; j.m., 3 to 0 mm.	No. 5 tr., 3 mm.	Close	30	16	60	.....	120	120	IV
1	Th. No. 2 breaker.	No. 2 rolls.	....	30	15	16	.....	.....	....	I
2	From No. 1 rolls.	No. 1 tr., ⅝ in.	....	30	15	24	.....	.....	....	III
3	J.m., ⅝ to ⅜ in.	No. 2 tr., ⅜ in.	Close	30	15	.....	.....	.....	....	IV
4	J.m., ⅜ to ⅛ in.; ov. No. 5 tr., ⅛ in.	No. 5 tr., ⅛ in.	Close	30	15	.....	.....	.....	....	IV
5	J.m., th. ⅛ in.	No. 5 tr., ⅛ in.	Close	30	15	.....	.....	.....	....	IV
1	J.m., ¼ in. to 0; ov. No. 5 tr., 0.1 in.	No. 5 tr., 0.1 in.	Close	22	16	50	10	.....	125	IV
1	J.m., 1 in. to 3 mm.; ov. No. 2 tr., 3 mm.	No. 2 tr., 3 mm.	Close	30	16	60	.....	65	100	IV
1	Th. Bl. 1½ in., on No. 1 tr., 4 mesh	No. 1 tr., 4 mesh	....	20	16	.....	.....	.....	....	II
1	Th. Bl., 1½ in.	No. 1 tr., 0.224 in.	½	27	14	22	.....	75	....	I
2	Ov. No. 1 tr., 0.224 in.	No. 1 tr., 0.224 in.	Close	20	10	30	.....	.....	....	III

1	Th. Bl., 1½ in.	No. 1 tr., 3 and 4 mesh.	¼	36	14	40	.....	100	125	I
2	Ov. of No. 1 tr., 3 and 4 mesh.	No. 1 tr., 3 and 4 mesh.	Close	36	14	37½	.....	60	100	III
1	Th. Bl., 1½ in.	No. 1 tr., 3 mesh.	½	27	14	40	.....	75	....	I
2	Ov. of No. 1 tr., 3 mesh.	No. 1 tr., 3 mesh.	Close	27	14	.....	.....	.....	....	III
1	Th. L., ¾ in.; th. No. 1 tr., 1 in.	No. 2 tr., 1/12 in.	Close	30	18	90	.....	.....	....	I
2	Ov. No. 2 tr., 1 to 1/12 in.	No. 2 tr., 1/12 in.	Close	30	18	100	.....	.....	....	III
3	Mid. of mag. separator, 1/12 in. to 0	No. 2 tr., 1/12 in.	Close	30	18	100	.....	.....	....	IV
1	From Buchanan fine breaker, 1 in.	No. 2 rolls.	½ to ¾	24	14	100	.....	60	....	I
2	From No. 1 rolls.	No. 2 tr. (p)	Close	18	12	130	.....	60	....	III
1	Th. Bl., ¾ in., on No. 2 tr., ¼ in.	No. 3 tr., 0.060 in.	Close	30	15	34	.....	90	120	II
2	Th. No. 2 tr., ¼ in., on No. 3 tr., 0.060 in.	No. 4 tr., 0.058 in.	Close	24	16	130	.....	25	40	II
3	Th. No. 9 tr., ¼ in., on No. 4 tr., 0.058 in.	No. 4 tr., 0.058 in.	Close	24	16	130	.....	25	40	II
1	Th. Bl., 1½ in.	Log washer.	1¼	30	14	25	.....	80	190	I
2	(q)	No. 1 tr., 6 mm.	1¼	24	12	30	.....	10	....	III

(*a*) Actual capacity is what the rolls actually do in 24 hours; maximum capacity is what it is estimated they would do if run at their maximum capacity. (*b*) Th. Bl., 20 mm.; No. 1 jig tailings, 20 to 10 mm.; No. 2 j.m., 10 to 2 mm. (*c*) Th. No. 1 tr., 15 mm. on No. 2 tr., 10 mm.; j.m., 10 to 0 mm. (*d*) One roll makes 44 revolutions, the other 45. (*e*) Th. gr., 1½ in., and Bl., 1½ in., on No. 1 tr., 0.252 in. (*f*) 102 revolutions per minute caused excessive wear. (*g*) 40 tons for hard ore, 60 for soft. (*h*) At 35 revolutions the rolls became glazed. (*i*) Ov. No. 1 tr., 12 mm.; j.m., 12 to 3 mm.; poor sand from trunking machine; poor settling table heads. (*j*) Ov. No. 1 tr., 7 mm.; jig tailings, 7 to 3 mm.; j.m., 3 to 0 mm. (*k*) This is the result of actual measurement. (*l*) Th. Dodge, 1¼ in., on No. 1 tr., 40 mm.; ov. No. 2 tr., 16 mm.; jig tailings, 40 to 60 mm. (*m*) j.m., 25 mm. to sand; ov. No. 5 tr., 2½ mm. (*n*) Jig middlings, ⅜ in. to 2½ mm.; ov. No. 6 tr., 2½ mm. (*o*) Jig tailings, 1½ in. to 15 mesh; ov. No. 2 tr., 1½ in. (*p*) This varies from ¼ in. down to 20 mesh. (*q*) Ov. No. 1 tr., 6 mm., which treats No. 1 roll stuff. (*r*) The roll classes referred to in the above table, I, II, III, IV are: I. Rolls which crush the product of a breaker; II. Rolls which crush the product of a breaker after it has gone through a trommel; III. Rolls which crush the product of a previous pair of rolls. This may or may not have been screened; IV. Rolls that are crushing jig middlings.

Tube Mill Data[1]

Relation between Per Cent. Ore and Solution, Fineness of Grinding and Horsepower

SCREEN ANALYSIS OF SAND FED TO TUBE MILLS, 12 FT. LONG, 5 FT. DIAMETER

On 20	On 30	On 40	On 60	On 80	On 100	On 120	On 150	Through 150
6.0	20.0	24.0	23.0	11.0	8.0	4.0	2.0	2.0

VARIABLE PEBBLE VOLUME, FIXED ORE AND SOLUTION

Pounds, pebbles	On 60	On 100	On 150	Through 150	Per cent., ore	Per cent., solution	Tons ore per 24 hr.	Indicated horsepower
3,000	42.5	27.5	8.0	22.0	63.72	36.28	172	18.80
6,000	46.5	23.5	8.0	22.0	70.17	29.83	172	20.37
9,000	42.0	26.0	8.0	24.0	74.29	25.71	172	22.5
12,000	32.0	32.0	12.0	24.0	60.00	40.00	172	32.16
15,000	29.0	30.0	14.0	27.0	65.38	34.62	172	39.13
16,800	18.0	36.0	12.0	34.0	66.67	33.33	172	42.88
18,000	3.5	29.0	16.0	51.5	66.67	33.33	172	47.16
19,000	4.0	28.0	13.0	55.0	66.67	33.33	172	51.45
20,000	9.0	32.0	15.0	44.0	71.88	28.12	172	56.28
21,000	6.0	30.0	13.5	50.5	71.88	28.12	172	60.10
22,000	6.0	29.0	15.0	50.0	71.88	28.12	172	65.39
23,000	6.0	30.0	14.0	50.0	70.37	29.63	172	77.18
24,000	3.0	27.0	16.0	54.0	70.96	29.04	172	68.61
24,500	4.0	26.0	13.0	57.0	68.18	31.82	172	69.68
25,000	3.0	26.0	14.0	57.0	66.67	33.33	172	75.04
26,000	5.0	28.0	15.0	52.0	70.00	30.00	172	68.60
27,000	8.0	33.0	14.0	45.0	68.00	32.00	172	64.85

VARIABLE ORE AND SOLUTION, FIXED PEBBLE VOLUME

Pounds, pebbles	Feed, inches	Tons ore per 24 hr.	On 60	On 100	On 150	Through 150	Per cent., ore	Per cent., solution	Indicated horsepower
20,000	3	172	7.0	32.0	13.0	48.0	64.71	35.29	56.4
20,000	3	172	13.0	35.0	11.0	41.0	66.67	33.33	54.28
20,000	3½	190	12.5	36.0	10.0	41.5	71.05	28.95	51.6
20,000	3½	190	14.0	34.0	12.0	40.0	67.86	32.14	54.8
20,000	4	216	16.0	34.0	14.0	36.0	68.18	31.82	53.2
20,000	4	216	14.0	36.0	16.0	34.0	69.70	30.30	49.4
20,000	4½	231	26.0	38.0	11.0	30.0	66.67	33.33	47.5
20,000	4½	231	30.0	30.0	10.0	30.0	72.22	27.78	43.5

[1] HOFMAN, "General Metallurgy."

Variable Solution, Fixed Pebble Volume and Ore Feed

Pounds, pebble	Ore feed, inches	Tons ore per 24 hr.	Tons solution per 24 hr.	On 60	On 100	On 150	Through 150	Per cent., ore	Per cent., solution	Indicated horse-power
20,000	3	172	68.0	12.5	36.0	10.0	41.5	71.43	28.57	45.0
20,000	3	172	75.0	13.0	34.0	12.0	41.0	69.56	30.44	48.9
20,000	3	172	90.0	8.0	30.0	13.0	49.0	65.67	34.33	55.8
20,000	3	172	92.0	8.0	32.0	14.0	46.0	65.20	34.80	57.4
20,000	3	172	98.0	9.0	33.0	12.0	46.0	63.78	36.22	58.0
20,000	3	172	111.0	8.0	33.0	13.0	46.0	60.70	39.30	56.9
20,000	3	172	113.0	7.0	31.0	13.0	50.0	60.44	39.56	55.0
20,000	3	172	136.0	8.0	34.0	12.0	46.0	55.71	44.29	55.8
20,000	3	172	196.0	7.0	32.0	14.0	47.0	47.10	52.90	59.0
20,000	3	172	207.0	5.5	30.5	13.0	51.0	45.40	54.60	62.3
20,000	3	172	268.0	8.0	32.0	12.0	48.0	38.90	61.10	62.3

Work of Grinding Pan and Tube Mill at Homestake[1]

	5-ft. grinding pans, 12,308 tons ground by 7 pans	5 × 14-ft. tube mill	
		Regular adjustment, medium feed	Special adjustment, heavy feed
Total tons ground per day	19.34 per pan	73	110.0
Tons ground per day to pass 200-mesh sieve	10.83 per pan	43	52.8
Water in feed, per cent.	80–90	38	38.4

	Head	Tails	Head	Tails	Head	Tails
Assay: gold value per ton	$2.66	$2.07	$2.49	$2.04	$2.49	$2.04
Sizing test: per cent. on 50 mesh	47	6.0	39.0	5.0	18.0	7.0
Through 50; on 80	34	14.0	38.0	12.0	49.0	15.0
Through 80; on 100	9	14.0	12.0	13.0	17.0	14.0
Through 100; on 200	6	26.0	7.0	28.0	11.0	26.0
Through 200	4	40.0	4.0	42.0	5.0	38.0
Tons ground per horse-power per day at one passage through grinder	....	2.30	......	1.94	......	2.92
To pass 100-mesh sieve	....	1.31	......	1.14	......	1.40
To pass 200-mesh sieve	....	0.83	......	0.74	......	0.97

Material consumed, pounds per ton	Iron, worn,	3.41	Pebbles,	1.66	Pebbles,	1.30
	Iron, scrapped	0.82				
	Total iron	4.23				

[1] Hofman, "General Metallurgy."

LANE LOW-SPEED CHILEAN MILL DATA[1]

Size of mill	Type of ore	Size of feed	Discharge	Consistency of overflow	Tons per 10 hrs.
10-ft.	Schist and hard quartz	1-in. ring size.	7½-in. overflow, no screen	80 % water	19.4
10-ft.	Same ore as above	1-in. ring size.	6-in. overflow, 30-mesh screen	80 % water	13.3
10-ft.	Hard, no talcose matter	¾-in.	7½-in. overflow	......	16.6
10-ft.	Tough, close-grained quartz	......	7-in. overflow	......	13.3
10-ft.	Chunderlee, Australia	1¼-in.	7-in. overflow	......	16.6
10-ft.	Chunderlee, Australia	1¼-in.	9-in. overflow	......	16.6
10-ft.	Hard quartz	......	6½-in. overflow	82–84 %	20–21
7-ft.	Brecciated quartz and andesite	......	10-in. overflow	80 % water	......

Size of mill	Screen analysis (not cumulative)							Rev. per. min.	Remarks
	+30	+40	+60	+80	+100	+120	−120		
10-ft.	0.428	0.858	2.376	5.346	13.848	3.656	73.182	......	......
10-ft.	none	none	0.87	3.959	13.017	5.952	76.049	8	Shows screen is a detriment
10-ft.	0.16	1.05	6.33	4.06	15.33	......	......	8	6.84 % on 150; 12.25 % on 200, 53.42 through 200
10-ft.	......	2.7	12.0	12.0	11.8	61.5		8	......
10-ft.	......	1.0	2.0	3.0	4.0	90.0		......	To compare effect of height of discharge
10-ft.	......	0.5	2.25	1.5	3.5	92.75		......	
10-ft.	......	3.0	12.0	11.0	13.0	61.0		8	Barnes-King Development Co., Mont.
7-ft.	......	......	......	3.4	12.5	......		7	Argonaut mine, Cal. 62 % minus = 200

[1] From original notes of ALEXANDER McLAREN, Litchfield, Conn.

MR. McLAREN says that at least 2 in. of pulp should be kept under the rollers of the slow-speed LANE mill. The slow-speed machine produces a large amount of fine material, but it is not a good regrinding machine.

Mill	Type	Rev. per min.	Capacity 24 hr.	Screen mesh	Feed	Ore	Size of product +30	+50	+60	+100	+150	+200	−200
Portland	Akron 6-ft.	34	124	30	¼-in.	Hard	.....	.....	.....	.....	.....	6.0	.....
Independence	Akron 6-ft.	33	120	30	⅜-in.	Hard	.....	21	.....	12.0	5	62.0	.....
Goldfield	Trent 6-ft.	32	75	30	4-mesh	Medium	4.0	10	.....	25.0	6	6.0	49.0
Mogul	Monadnock	....	105	30	1½-in.	Hard	14.5	....	17.8	12.6	.....	15.7	39.4

One horsepower will crush from 1 to 2¼ tons of ore in the slow-speed mill.

[1] Private notes of H. A. Megraw.

Crushing With Gyratory Crushers

Abbreviations.—Br. = breakers; c. = comet; cap. = capacity; est. = estimated; g. = Gates; griz. = grizzly; hp. = horsepower; in. = inches; L. = Lowry; max. = maximum; No. = number.

Beaker No.	Pattern	No. used	Size	Revolutions per minute: Of pulley	Of head	Size of feed	Size crushed to inches	Actual cap. per br. per 24 hours, tons	Est. max. cap. per 24 hours, (a) tons	Repairs besides wearing parts	Est. hp. required	Head raised by
1	C.	1	D	320	160	Mine ore	2½	200	(b)960	(c)	(d)30	Worm gear.
1	G.	1	4	340	170	Mine ore over 1¼-in. griz.	2½	250	960	(e)	20–25	.....
1	G.	2	3	425	212	Mine ore over 1½-in. griz.	1½	110	.....	.....	.....	.....
1	G.	1	3	500	250	Mine ore over 1-in. griz.	1	200	480	(f)	20	.....
1	C.	1	6	.....	.....	Mine ore over 1½-in. griz.	2	75	.....	.....	.....	.....
1	G.	1	3	.....	.....	Mine ore	2	17	.....	.....	12	Screw to 6 in.
1	G.	1	3	425	212	Mine ore over ½-in. griz.	1	125	380	(g)	.....	Screw to 6 in.
1	G.	3	6	.....	.....	Mine ore	1½	200	.....	.....	.....	Screw to 6 in.
1	C.	2	D	.....	.....	Mine ore	1 to 1½	60	.....	.....	.....	Shims up to 6 in.
1	C.	1	D	400	200	Mine ore over 1½-in. griz.	3	100	.....	(h)	40	Worm gear.
4	L.	1	.....	.....	.....	(i)	¾	.....	.....	.....	.....	.....

(a) These are estimates by the mill managers; for capacities quoted by manufacturers, see Tables 19 and 20. (b) This can probably crush 1440 tons in 24 hours. (c) Repairs, oil and other incidentals, $200 per year. (d) This is the result of actual measurement. (e) None except occasional babbitting. (f) Babbitt eccentric every 6 months. (g) Bevel year and pinion gear. (h) Babbitting bearings. (i) Through No. 3 breaker on No. 1 trommel, 1 in.

Hardinge Mill Data

No.	Diameter of mill, feet	Length cylinder, inches	Type	Mining company	Gangue	Material	Charge, balls or pebbles, pounds	Speed, rev. per min.
122	4.5	13	Ball	Vipond Porcupine Mines Co.	Quartz and basalt	Ore from mill bin	4,000	33
107	6*	16	Ball	Miami Copper Co.	Siliceous porphyry	Ore from mill bin	8,000	28
155[a]	6	16	Ball	Britannia M. & S. Co.	Quartzose, very hard	Jig tailing	8,200	28
192	6	16	Ball	McIntyre Porcupine Mines	Quartz and schist	Rock-crusher product	8,000	28
156	6	16	Ball	McIntyre Porcupine Mines	Quartz and schist	Rock-crusher product	8,000	28
191	6	16	Ball	Buckhorn Mines Co.	Decomposed porphry and basalt	Rock-crusher product	8,000	28
121	6	22	Pebble	Bunker Hill & Sullivan	Quartzite and siderite.	Middling from jigs and tables	4,000(?)	32
113	6	72	Pebble	Vipond Porcupine Mines	Quartz and basalt	Oversize Colbath classifier.	9,000	27
108	8	22	Pebble	Miami Copper Co.	Altered schist	Product 16 by 42-in. rolls.	10,000	27
80	8	22	Pebble	Miami Copper Co.	Altered schist	Product 16 by 42-in. rolls.	10,000	27
109	8	22	Pebble	Federal M. & S. Co.	Quartzite and siderite.	Jig middling	10,000	28
75	8	22	Pebble	Federal M. & S. Co.	Quartzite and siderite.	Coarse Wilfley middling	10,000	28
136	8	22	Pebble	Federal M. & S. Co.	Quartzite and siderite.	Jig middling	10,000	28
150	8	22	Pebble	Vieille Montagne Zinc Co.	Siliceous limestone	Jig middling	6,000	29.5
34	8	22	Pebble	Calumet & Hecla	Conglomerate	Jig tailing	6,000	27
33	8	30	Pebble	Copper Range Consol	Amygdaloid	Jig tailing	10,000	28
142	8*	36	Pebble	Arizona Copper Co.	Porphyry	Screened roll product	10,500	29
135	7	144	Tube	Federal M. & S. Co.	Quartzite	Wilfley middling	18,000	22.25

* Mill overloaded.

[a] Note R.M.E. [b] — 100 mesh. [c] — 150 mesh.

HARDINGE MILL DATA. *Continued*

No.	Tons, per 24 hr.	Horsepower	Tons per horsepower	Feed		Energy units	Discharge		Per cent. −200 mesh	Energy units	Difference, E.U.	Relative mech. effi. (R.M.E.)	Per cent., water in feed	Elevation of feed end, inches	Pebbles or balls, pounds per ton
				All pass, mm.	Average size, mm.		All pass, mm.	Average size, mm.							
122	48	16	3.0	50.8	12.01	280.2	6.3	0.26	40.2[b]	1,423.4	1,143.2	34.3	50	......	......
107	351	35	10.0	38.1	6.01	665.3	12.7	0.86	21.8	1,247.0	581.7	58.3	50	2	0.578
155[a]	251	39	6.4	6.35	1.28	912.5	6.35	0.24	34.2[b]	1,432.7	520.2	33.5	40	0	0.72
192	150	36	4.2	50.8	12.7	313.1	6.35	0.19	41.07	1,705.1(?)	1,392.0	58.0	50	1.25	0.5
156	150	36	4.2	50.8	10.04	182.5	1.65	0.25	37.2	1,330.0	1,147.5	47.8	60	1.25	0.5
191	160	33.25	4.8	38.1	7.09	525.4	3.2	0.16	28.0[c]	1,535.6	1,010.2	48.6	80	1.5	0.45
121	60.3	16(?)	5.2	3.0	0.58	1,092.8(?)	0.36	0.09	41.8	1,686.9	594.1	30.9	75(?)	0.5	......
113	40	30	1.3	3.0(?)	0.65	1,154.6	0.24	0.05	68.8	1,823.4	668.8	9.19	50	0.0	......
108	101	36	2.8	25.4	1.36	973.8	1.65	0.19	35.9	1,573.2	599.4	16.8	63	1.5	......
80	180	36	5.0	12.7	1.1	990.3	1.65	0.17	38.1	1,591.3	601.0	30.0	62.5	1.5	......
109	112.5	35.8	3.1	4.7	1.12	943.2	1.65	0.14	25.0	1,594.7	651.5	20.5	60	0.0	2.0
75	99.36	35.3	2.8	5.0	0.56	1,040.9	0.83	0.09	67.0	1,750.6	709.7	20.0	55	0.0	1.5–2
136	111.5	35.3	3.3	4.7	0.99	986.4	0.83	0.12	39.0	1,649.4	663.0	21.7	71.8	2.0	2.0
150	120	35(?)	3.4	12.7	3.15	632.5	2.4	0.21	13.5	1,492.3	859.8	29.5	......	4.0	......
34	42.5	35.5	1.2	6.35	0.56	1,195.6	1.65	0.08	40.8	1,614.7(?)	419.1	5.0	40	0.0	2.0
34	65	46(?)	1.4	6.35	1.72	825.8	0.83	0.10	34.0	1,652.9	827.1	11.7	64	1.0	2.5
142	208	55	3.8	12.7	2.89	786.5	2.36	0.27	34.7	1,502.1	715.6	27.1	59	0.0	2.4
135	124	86	1.4	2.3	0.41	1,051.4	0.83	0.11	44.5	1,690.2	638.8	9.2	58.8	0.0	4–5

The "energy units" are calculated on STADLER's rules (cf. "*Eng. and Min. Journ.*," Nov. 21 and 28, 1914). See for another basis ARTHUR GATES on the "Crushing-Surface Diagram, "*Eng. and Min. Journ.*," May 24, 1913, and Apr. 18, 1914, and the "Work of Crushing", by ARTHUR F. TAGGART, "*Trans. A. I. M. E.*," February, 1914. Either method gives comparative results, one must be wrong in absolute units, and the arguments are too voluminous to reprint here.

HARDINGE MILL DATA[1]

	6 ft. by 16-in. ball mill	8 ft. by 22-in. pebble mill
Average maximum size of feed, mm	44.5	9.7
Average size of feed, mm	9.0	1.26
Average maximum size of product, mm	6.0	1.5
Average size of product, mm	0.37	0.14
Average per cent. of −200 mesh in product	28.9[2]	37.0
Average per cent. of −200 mesh in product, no slope	....	44.3
Average per cent. of −200 mesh in product, 0.5 to 4 in. slope		31.6
Reduction ratio, range	7 to 67	6 to 15
Reduction ratio, average	39.6	8
Average size of product, no slope, mm	....	0.10
Average size of product, slope 0.5 to 4 in.	....	0.17
Average tonnage	203	110
Average tonnage at no slope	....	85
Average tonnage at 0.5 to 4 in. slope	....	128
Average horsepower	35.06	35.6
Average charge, balls or pebbles, tons	4	4.5
Average ball or pebble consumption, pounds per ton	0.51	1.94
Average relative mechanical efficiency	53.2	20.5
Average percentage of water in feed	60	58.7
Average revolutions per minute	28	27.8

[1] *Trans. A. I. M. E.*, July, 1915.
[2] Nos. 155 and 191 estimated.

Stamp Milling

Stamp order—Homestake 1 4 2 5 3
Stamp order—Brazil 1 5 2 4 3
Drops per minute—theoretical maximum on 9-in. drop—95.
Drops per minute—theoretical maximum on 8-in. drop—100 to 108.

STAMP MILL DROPS[1]

Length of drop, inches	Number of drops per minute	Total inches drop per minute	Comparative power required	Number units crushing force per drop	Number units crushing force per minute
6	115	690	100.00	1.0000	115.00
7	108	756	109.57	1.1667	126.00
8½	100	850	123.19	1.4167	141.67
10½	90	945	136.96	1.7500	157.50

[1] McFARREN'S "Stamp Milling and Amalgamation." Courtesy of the "*Mining and Scientific Press.*"

HORSEPOWER PER STAMP REQUIRED BY THE 5-STAMP BATTERY[1]

Height of Drop in Inches and Number of Drops per Minute

A. NOMINAL HORSEPOWER TO RAISE STAMPS WITHOUT FRICTION

Weight of stamp in pounds	5 in. 115 drops	6 in. 110 drops	7 in. 105 drops	8 in. 100 drops	9 in. 95 drops	10 in. 90 drops
850	1.234	1.417	1.578	1.717	1.835	1.932
900	1.307	1.500	1.670	1.818	1.943	2.045
950	1.379	1.584	1.764	1.919	2.052	2.159
1000	1.452	1.667	1.856	2.020	2.159	2.273
1050	1.525	1.750	1.949	2.121	2.267	2.386
1100	1.597	1.833	2.042	2.222	2.375	2.500
1150	1.670	1.917	2.134	2.323	2.483	2.614
1200	1.742	2.000	2.227	2.424	2.591	2.727
1250	1.815	2.083	2.320	2.525	2.699	2.841
1300	1.888	2.167	2.413	2.626	2.807	2.955
1350	1.960	2.250	2.506	2.727	2.915	3.068
1400	2.033	2.333	2.598	2.828	3.023	3.182
1450	2.105	2.417	2.691	2.929	3.131	3.295
1500	2.178	2.500	2.784	3.030	3.239	3.409
1550	2.251	2.583	2.877	3.131	3.347	3.523
1600	2.323	2.667	2.970	3.232	3.455	3.636
1650	2.396	2.750	3.062	3.333	3.563	3.750
1700	2.468	2.833	3.155	3.434	3.670	3.864
1750	2.541	2.917	3.248	3.535	3.778	3.977
1800	2.614	3.000	3.341	3.636	3.886	4.091
1850	2.686	3.083	3.434	3.737	3.994	4.204
1900	2.759	3.167	3.527	3.838	4.102	4.318
1950	2.831	3.250	3.619	3.939	4.210	4.432
2000	2.904	3.333	3.712	4.040	4.318	4.545
2050	2.978	3.417	3.805	4.141	4.426	4.659
2100	3.050	3.500	3.898	4.242	4.533	4.772
2150	3.123	3.583	3.990	4.343	4.641	4.886
2200	3.194	3.666	4.084	4.444	4.750	5.000

[1] McFARREN's "Stamp Milling and Amalgamation." If the number of drops used varies from that in the table, multiply the horsepower taken from the table by the number of drops used, and divide by the number of drops in the table.

B. Horsepower Applied to Cam-shaft Pulley
(1.202 times A)

Weight of stamp in pounds	5 in. 115 drops	6 in. 110 drops	7 in. 105 drops	8 in. 100 drops	9 in. 95 drops	10 in. 90 drops
850	1.483	1.703	1.897	2.064	2.206	2.322
900	1.571	1.803	2.008	2.185	2.336	2.459
950	1.658	1.903	2.119	2.307	2.465	2.595
1000	1.745	2.003	2.231	2.428	2.595	2.732
1050	1.833	2.103	2.343	2.550	2.725	2.868
1100	1.920	2.204	2.454	2.671	2.855	3.005
1150	2.007	2.304	2.566	2.793	2.984	3.142
1200	2.094	2.404	2.677	2.914	3.114	3.278
1250	2.182	2.504	2.789	3.035	3.244	3.415
1300	2.269	2.604	2.900	3.157	3.374	3.551
1350	2.357	2.704	3.012	3.278	3.504	3.688
1400	2.444	2.805	3.123	3.400	3.633	3.825
1450	2.532	2.905	3.235	3.521	3.763	3.961
1500	2.619	3.005	3.347	3.642	3.893	4.098
1550	2.706	3.105	3.458	3.764	4.023	4.234
1600	2.793	3.205	3.570	3.885	4.152	4.371
1650	2.881	3.305	3.681	4.007	4.282	4.507
1700	2.968	3.406	3.793	4.128	4.412	4.644
1750	3.055	3.506	3.904	4.250	4.542	4.781
1800	3.143	3.606	4.016	4.371	4.671	4.917
1850	3.230	3.706	4.127	4.492	4.801	5.054
1900	3.317	3.806	4.239	4.614	4.931	5.190
1950	3.404	3.906	4.350	4.735	5.061	5.327
2000	3.492	4.007	4.462	4.857	5.190	5.464
2050	3.579	4.107	4.574	4.978	5.320	5.600
2100	3.667	4.207	4.685	5.099	5.450	5.737
2150	3.754	4.307	4.797	5.221	5.580	5.873
2200	3.840	4.408	4.908	5.342	5.710	6.010

C. APPROXIMATE TOTAL HORSEPOWER
(1.35 times A)

Weight of stamp in pounds	5 in. 115 drops	6 in. 110 drops	7 in. 105 drops	8 in. 100 drops	9 in. 95 drops	10 in. 90 drops
850	1.666	1.913	2.130	2.318	2.477	2.608
900	1.764	2.025	2.255	2.454	2.623	2.762
950	1.862	2.138	2.380	2.591	2.769	2.915
1000	1.960	2.250	2.506	2.727	2.915	3.069
1050	2.058	2.363	2.631	2.863	3.060	3.222
1100	2.156	2.475	2.756	3.000	3.206	3.375
1150	2.254	2.588	2.881	3.136	3.352	3.529
1200	2.352	2.700	3.007	3.272	3.498	3.682
1250	2.450	2.813	3.132	3.409	3.643	3.836
1300	2.548	2.925	3.257	3.545	3.789	3.989
1350	2.646	3.038	3.383	3.681	3.935	4.143
1400	2.744	3.150	3.508	3.818	4.081	4.296
1450	2.842	3.263	3.633	3.954	4.226	4.449
1500	2.940	3.375	3.758	4.091	4.372	4.603
1550	3.038	3.488	3.884	4.227	4.518	4.756
1600	3.136	3.600	4.009	4.363	4.663	4.910
1650	3.234	3.713	4.134	4.500	4.809	5.063
1700	3.332	3.825	4.260	4.636	4.955	5.217
1750	3.430	3.938	4.385	4.772	5.101	5.370
1800	3.528	4.050	4.510	4.909	5.246	5.523
1850	3.626	4.163	4.635	5.045	5.392	5.677
1900	3.724	4.275	4.761	5.181	5.538	5.830
1950	3.822	4.388	4.886	5.318	5.684	5.984
2000	3.920	4.500	5.011	5.454	5.829	6.137
2050	4.018	4.613	5.136	5.590	5.975	6.291
2100	4.116	4.725	5.262	5.727	6.121	6.444
2150	4.214	4.838	5.387	5.863	6.266	6.597
2200	4.312	4.950	5.512	6.000	6.412	6.750

Mud Sills.—These vary from three to four and range from 12 × 12 to 24 × 24 in. These are used only with old-style wooden foundations.

Cross Sills.—These range from 12 × 16 in. to 20 × 24 in.

MORTAR BLOCKS[1]

Depth		Length		Width		Foundation	Material	How fastened
Ft.	In.	Ft.	In.	Ft.	In.			
12	0	......	......	2	8	......	2-in. plank on end (*a*)	......
9	0	4	10	2	4	Solid rock	2-in. planks	By wire spikes.
14	0	4	10½	2	6	Concrete (*b*)	30 × 30-in. timbers	......
12	0	5	0	2	0	Solid rock	......	......
12	9	5	0	2	6	Solid rock	30 × 30-in. timbers	By 1-in. bolts.
14	0	4	10	2	6	Solid rock	28 × 30-in. timbers	......
19	0	4	8	2	2	Solid rock	2 × 12-in. plank	By 30-penny spikes.
18	0	(*c*) 28	4	2	6	Solid rock	Spruce 6 × 2-in. and 12 × 2 (*d*)	By 5-in. spikes.
9	2	4	7	2	4	......	Three timbers	......
10	0	(*e*) 13	0	2	0	Concrete	......	By six 1-in. bolts.
9	0	4	10	2	5	Solid rock (*f*)	Pine timbers, 29 × 29 in.	By three 1¼-in. bolts.
10	0	4	6	1	4	......	......	......
9	4	4	7	2	4	Solid rock	Three timbers	......
14	0	(*e*) 13	0	2	6	Solid rock	......	......
10	0	5	0	2	0	Solid rock	24 × 30-in. timbers	......
9	0	(*e*) 10	0	2	6	Solid rock	18 × 12-in. timbers	......
12	0	4	8	2	2	Solid rock	Planks	......

[1] R. H. RICHARDS, "Ore Dressing," Vol. I.

(*a*) With width parallel to cam shaft. (*b*) 2 ft. thick. (*c*) For four batteries. (*d*) Planed and joined. (*e*) Length over all. The author is in doubt whether these are individual or combined mortar blocks. (*f*) Levelled by sand.

Steam Stamps

The steam stamp is one in which a vertical stamp shaft is forced down to strike its blow, and lifted up preparatory to the next by means of a steam piston. The large ones are used solely in the Michigan Copper Country. A small steam stamp, the Tremain, built by the Gates Iron Works, has been devised for treating gold ore, the idea being that they would be light to pack for the capacity obtained, and could be quickly mounted and dismounted.

Standard Mining Screens[1]

Mesh	Wire No.	Diam. of wire, inches	Diam. of aperture, inches	Equivalent in millimeters	Per cent. of opening
1″	3	0.2437	0.7563	19.81	....
¾″	4	0.2253	0.5247	13.33	....
⅝″	5	0.2070	0.4180	10.62	....
2 mesh	8	0.1620	0.3380	8.59	....
2½	9	0.1483	0.2517	6.39	....
3	10	0.1350	0.1983	5.04	....
3½	11	0.1205	0.1652	4.20	....
4	12	0.1055	0.1445	3.67	....
4½	13	0.0915	0.1307	3.32	....
5	13	0.0915	0.1085	2.76	....
6	14	0.0800	0.0867	2.20	....
7	15	0.0720	0.0709	1.80	....
8	16	0.0625	0.0625	1.59	....
9	17	0.0540	0.0571	1.45	....
10	18	0.0475	0.0525	1.33	....
12	19	0.0410	0.0423	1.07	25.80
14	20	0.0348	0.0366	0.93	26.01
16	22	0.0286	0.0339	0.86	30.47
18	23	0.0258	0.0298	0.76	30.24
20	24	0.0230	0.0270	0.69	29.16
22	25	0.0204	0.0251	0.64	31.35
24	26	0.0181	0.0286	0.60	32.27
30	28	0.0162	0.0171	0.43	27.03
40	31	0.0132	0.0118	0.30	21.15
50	34	0.0104	0.0096	0.24	25.00
60	36	0.0090	0.0077	0.20	18.45
64	37	0.0085	0.0071	0.18	....
70	38	0.0080	0.0063	0.16	16.42
80	40	0.0070	0.0055	0.14	19.36

Rittinger's sizes: Fine table ore, finer than 0.25 mm.; coarse table ore, 0.25–1 mm.; fine jigging ore, 1–4 mm.; coarse jigging ore, 4–16 mm.; lump ore, 16–64 mm.

[1] R. H. Richards, "Ore Dressing."

Tyler Standard Screen Scale

Ratio $\sqrt{2}$ or 1.414		Mesh	Diam. wire, dec. of an inch
Opening in inches	Opening in millimeters		
1.050	26.67	....	0.149
0.742	18.85	....	0.135
0.525	13.33	....	0.105
0.371	9.423	....	0.092
0.263	6.680	3	0.070
0.185	4.699	4	0.065
0.131	3.327	6	0.036
0.093	2.362	8	0.032
0.065	1.651	10	0.035
0.046	1.168	14	0.025
0.0328	0.833	20	0.0172
0.0232	0.589	28	0.0125
0.0164	0.417	35	0.0122
0.0116	0.295	48	0.0092
0.0082	0.208	65	0.0072
0.0058	0.147	100	0.0042
0.0041	0.104	150	0.0026
0.0029	0.074	200	0.0021

I. M. M. Standard Laboratory Screens[1]

Mesh, linear inch	Diameter of wire		Aperture		Screening area, per cent.
	In.	Mm.	In.	Mm.	
5	0.1	2.540	0.1	2.540	25.00
8	0.063	1.600	0.062	1.574	24.60
10	0.05	1.270	0.05	1.270	25.00
12	0.0417	1.059	0.0416	1.056	24.92
16	0.0313	0.795	0.0312	0.792	24.92
20	0.025	0.635	0.025	0.635	25.00
30	0.0167	0.424	0.0166	0.421	24.80
40	0.0125	0.317	0.0125	0.317	25.00
50	0.010	0.254	0.01	0.254	25.00
60	0.0083	0.211	0.0083	0.211	24.80
70	0.0071	0.180	0.0071	0.180	24.70
80	0.0063	0.160	0.0062	0.157	24.60
90	0.0055	0.139	0.0055	0.139	24.50
100	0.005	0.127	0.005	0.127	25.00
120	0.0041	0.104	0.0042	0.107	25.40
150	0.0033	0.084	0.0033	0.084	24.50
200	0.0025	0.063	0.0025	0.063	25.00

[1] E. A. Smith, "Sampling and Assay of the Precious Metals."

SIZES OF ROUND AND SLOT-PUNCHED PLATE SCREENS

Needle number of screen	Approximate mesh of wire cloth to which openings correspond	Width of slot or diameter of hole in inches	Width of slot or diameter of hole in millimeters
1	12	0.058	1.47
2	14	0.049	1.25
3	16	0.042	1.07
4	18	0.035	0.89
5	20	0.029	0.74
6	25	0.027	0.69
7	30	0.024	0.61
8	35	0.022	0.56
9	40	0.020	0.51
10	50	0.018	0.46
11	55	0.0165	0.42
12	60	0.015	0.38
13	70	0.013	0.33

The needle-number is the number of the standard sewing needle that will just pass the screen.
Table taken from MACFARREN's "Stamp Milling and Amalgamation."

CONCENTRATION

The processes by which concentration may be carried on are: hand picking, wet-gravity separations (jigging, vanning, etc.), amalgamation, magnetic, electrostatic, pneumatic, adhesion or flotation, crushing and screening, decrepitation and screening, by varying electric conductivity. A short list of the chief concentrating machinery follows:

Ball-Norton Magnetic Separator.—This consists of two revolving drums. Within each of these drums is a series of stationary electromagnets extending the working length of the drum, but corresponding only to a portion of the periphery. The ore is fed on the top of the first drum, and as the drum revolves, the magnetic particles adhere to it, while the non-magnetic fall into a tailings bin below. The magnetic particles, as soon as the portion of the drum on which they are passes beyond the magnets, are thrown off by centrifugal force against the second drum. This either rotates faster or has a weaker magnetic field than the first drum, so that those particles least strongly attracted by the first drum fall from the second, making a middlings product.

Bartlett Table.—This is a three-deck WILFLEY, the second deck re-treating the material from the first and the third deck re-treating the material from the second. An increasing amount of wash water is used on the successive decks.

Bilharz, Corning, Luhrig and Stein Tables.—These are side-bump tables having a table surface made of an endless traveling belt which has a plane surface.

Bumping and Jerking Tables.—These machines use mechanical agitation to bring the light and the heavy grains into their respective layers on a washing surface, and they use a bumping or jerking action to convey the heavy grains to one side or the other of the machine, while the current of surface water conveys the light grains to another side or end. They may be either side-bump, having the bump or jerk at right angles to the flow of the water, or end-bump, having the bump or jerk in the opposite direction from the flow of the water. See RITTINGER, BILHARZ, WILFLEY, BARTLETT and OVERSTROM for side-bump tables. For further information see these types and "end-bump" tables.

Canvas Tables.—These are inclined rectangular tables covered with canvas. The pulp, to which clear water is added if necessary, is evenly distributed across the upper margin. As it flows down, the concentrates settle in the corrugations of the canvas. After the meshes are filled, the pulp feed is stopped, the remaining quartz is washed off with clear water, and finally the concentrates removed (by hose or brooms).

Card Concentrator.—A table made of two planes having a flexible joint between them dividing the table into two nearly equal triangles, forming a diagonal line along which concentrates and tailings part company.

Conkling Magnetic Separator.—The ore is fed on a conveying belt which passes under magnets, below which belts run at right angles to the line of travel of the main belt. The magnetic particles are lifted up against these cross belts and are thus removed.

Deister Table.—This is a riffled table in which the angle between the line of termination of the riffles and the direction of motion is not so acute as in the WILFLEY. It is also wider and shorter. The top is rhomboidal.

Ding's Magnetic Separator.—Material is fed up a vibrating conveyor and passes through successive zones of separation. These zones are covered by the rims of rotating wheels which carry secondary magnets. These carry the magnetic particles out of the field, are demagnetized, and drop the concentrates.

Dodd Buddle.—A round table resembling in operation a WILFLEY table, and also like the PINDER table (*q.v.*) except that it is convex instead of concave. The table does not revolve but has a peripheral jerking motion imparted to it circumferentially by means of a toggle movement.

End-bump Tables.—The heavy and light minerals are separated by agitation and are propelled up the slope of the table by bumping action, but the wash water carries down the surface quartz at a higher speed than the bump can send it up. The Gilpin County, IMLAY and Golden Gate concentrators are the chief types.

Ferraris Table.—This table has a plane rubber belt traveling between rollers furnished with broad flanges to keep the belt in line. It has a slope from side to side. The feed is at an upper corner, and washing is by jets directed across the table.

Film-sizing Tables.—These use the relative transporting power of a film of water flowing on a quiet surface, which may be either rough or smooth, to act upon the particles of a water-sorted product. The smaller grains, of high specific gravity, are moved down the slope slowly or not at all by the slow under-current; the larger grains, of lower specific gravity, are moved rapidly down the slope by the quick upper current. These tables may be classified as: Surface tables, from which the products are removed before they have formed a bed, so that the washing is always done on the same surface; and building tables or buddles, on which the products are removed after they have formed a bed.

Frue Vanner.—This consists essentially of a rubber belt traveling up a slight inclination. The material to be treated is washed by a constant flow of water while the entire belt is meanwhile shaken from side to side. Other vanners of the side-shake type are the TULLOCH, JOHNSTON and NORBOM.

Gates Canvas Table.—A large form of inclined canvas table in which the pulp is first classified, then distributed along the upper edge of the table. The concentrates are caught in the warp of the canvas and after this is full, treatment must be stopped while the concentrates are swept or sluiced off.

Gröndal.—A magnetic separator consisting of a vertical revolving cylinder made up of rings of cast iron with the spaces between containing the wires for the electric current. Each ring is so magnetized as to be a little stronger than the one above. There is another cylinder of wood studded with soft wrought-iron pegs, a ring of pegs being opposite each cast-iron ring. The magnetic portion of the ore (usually crushed below 12 mesh) is carried around on the cast-iron rings until it gets near the pegs, to which it jumps because of their induced magnetism. It is then carried on these pegs out of the magnetic field and thrown off.

Hallett Table.—This is like the WILFLEY except that the tops of the riffles are in the same plane as the cleaning planes and the riffles are sloped toward the wash-water side.

Hancock Jig.—A jig with movable sieve having both an up-and-down and a reciprocating motion.

Harz or Plain Eccentric Jig.—One in which pulsion is given intermittently with suction. The periods devoted to them are about equal.

Huff Separator.—An electrostatic machine depending on the repelling and attracting action of electrically charged particles. The feed is passed over a roller, and the constituents take various electrical charges according to conductivity and are repelled accordingly. This machine is superseding the old BLAKE type.

Isbell Table.—A table with a reciprocating motion in which there is no cross wash water. The bed of pulp is deep as in a jig, and heavy material goes to the bottom. The concentrates and tailings are then split by means of a cut-out which can be adjusted vertically to skim at any height desired. The riffles make an angle of about 20° with the line of motion of the table.

James Concentrator.—The table deck is divided into two sections, flexibly joined together on a line oblique to the line of motion of the table. One section is riffled for the coarse material while the other section is smooth, to allow the settling of the fine particles which will not settle on a riffled surface. By means of the joint, the slope of the sections can be varied independently.

Johnston Vanner.—The chief difference between this and a FRUE (*q.v.*) is that the belt is given an undulating motion, designed to prevent sands from piling up against the edges of the belt.

Kieves.—These are strong tubs with sides flaring upward, in which separation is effected by mechanical agitation in a deep mass of thick pulp. Stirring paddles are used for preliminary mixing, and hammers or heavy striking bars for the final separation. They are used to finish the concentration of fine products that are nearly rich enough to ship.

Log Washer.—This is a slightly slanting trough in which revolves a thick shaft or log, carrying blades obliquely set to the axis. Ore is fed in at the lower end, water at the upper. The blades slowly convey the lumps of ore uphill against the current, while any adhering clay is gradually disintegrated and floated out the lower end.

Overstrom Table.—A WILFLEY squeezed out into a diamond shape (rhomboid), thus eliminating the waste corners.

Pinder Concentrator.—A revolving table on which are tapering spiral copper cleats on a linoleum cover. The tailings are washed over the riffles and off the edge while the concentrates are delivered at the end of the riffles.

Richard's Pulsator Jig.—An outcome of the pulsator classifier, in which a pulsating column of water is used in the jig.

Rittinger Table.—A side-bump table with plane surface, using a cam, spring and bumping post.

Spitzlutte.—This is a classifying device consisting of a V-shaped box, as distinguished from the pyramidal boxes of the spitzkasten. Classification is dependent on the force of a stream of water admitted at the bottom.

Sutton, Steele and Steele Dry Table.—A concentrator of the WILFLEY type in motion, but instead of using water, stratification is by means of rising currents of air. The heavy grains are pushed forward by the head motion, while the lighter grains roll or flow down the slope toward the tailing side.

Triumph Concentrator.—This machine resembles a FRUE vanner (*q.v.*), but the shaking motion is endwise instead of side to side.

Trough Washer.—This is used to float adhering clay or fine stuff from the coarser portions of an ore. In its simplest form it is a sloping wooden trough, 1½ to 2 ft. wide, 8 to 12 ft. long and 1 ft. deep, open at the tail end, but closed at the head end.

Ullrich Magnetic Separator.—These machines have powerful electromagnets of wedge section. The material is treated on rolls on which magnetism is induced. They consist of alternate

disks of soft iron and some non-magnetic material. The ore is fed over the first roll, which removes the most magnetic material, and the tailings go on to the second which is weaker, where a second separation is made.

Vanner.—See FRUE vanner for general description of the side-shake type. There is also an end-shake type, which includes the Triumph concentrator, EMBRY concentrator, and WOODBURY vanner, and a gyrating type, the ELLIS. A 4-ft. vanner may take up to 13 gal. of water per minute and the weight of water to dry sand may rise to 10.7:1. The pulp bed may be as much as 0.45 in. thick.

Wetherill's Magnetic Separator.—Parallel form. Two flat belts, the upper of which is the wider, run parallel to each other. The magnets are long and set obliquely to the belts. Consequently magnetic particles are drawn up against the upper belt, more diagonally out and as they pass beyond the influence of the magnets, fall from the edge past the other belt into a concentrates bin. Another form operates by belts moving across the line of travel of the main belt.

Wilfley Slimer.—A form of shaking canvas table which is given a vanner motion.

Wilfley Table.—A side jerk table with a riffled surface. The light and heavy grains are separated into layers by agitation, and the jerking action then throws the heavy grains toward the head end, while the light grains are washed down over the cleats into the tailings box. The table tapers toward the head end, and the riffles are progressively longer toward the tailings side. The DODD, CAMMETT, HALLETT and WOODBURY are very like it.

Woodbury Jig.—A jig with a plunger compartment at the head end, so that the material is given a classification in the jig.

Woodbury Table.—A table of the general WILFLEY-OVERSTROM-CARD type, with the riffles parallel to the tailing side, and a hinged portion without riffles (unlike the Card). The table top is a rhomboid, and the riffles gradually shorten as they near the tailings side.

CONCENTRATING AND CYANIDING MACHINERY

The following list includes the most important types of concentrating and cyaniding machinery not already described under crushing and concentrating equipment.

Akins Classifier.—A classifier of the free-settling type, in which the heavy material is driven up an inclined plane by means of an interrupted-flight screw conveyor.

Blaisdell Reclaiming Apparatus.—Apparatus for automatically discharging sand tank having a central bottom opening. Consists of a central vertical shaft carrying four arms fitted with round plow disks. Sand is plowed toward central opening and discharged on a conveyor belt.

Blaisdell Loading Machinery.—Apparatus for loading sand tanks. Consists of a rapidly revolving disk with curved radial

vanes. Disk is hung on a shaft in tank center. Sand dropped on disk is distributed over the entire tank area.

Brown Tank.—As ordinarily used it is a cylindrical tank 45 ft. high and 15 ft. in diameter, ending at the lower end in a 60° cone. Within the tank is a hollow column about 15 in. in diameter extending from about 18 in. of the bottom to within about 8 in. of the top. A 1½-in. air pipe discharges air upward at and into the tube. The apparatus works on the air-lift principle, the pulp in the tube being lightened by the air, flowing upward, and being discharged at the top, more pulp flowing in at the bottom to take its place.

Bunker Hill Screen.—A rotating screen shaped like a funnel. Material is delivered inside the funnel, undersize passing through the screen while the oversize is discharged through the funnel neck.

Burt Filter.—This is a stationary, intermittent filter in which the leaves are suspended vertically in a round tank set on a considerable incline. The leaves are therefore ellipses. The slime cake is discharged by introducing air and water into the interior of the leaf. There is also a newer Burt filter of the continuous rotating-drum type.

Butters Filter.—This is a stationary, intermittent vacuum filter. The leaves are arranged in a box having a pyramidal bottom. When the pulp is introduced a vacuum is applied until a cake from 1 to 2 in. in thickness is formed. The surplus solution is then removed from the box and wash solution or water introduced. After removing the wash solution, either the box is filled with water or the cake dropped and sluiced out.

Callow Screen.—A classifying screen using the traveling-belt principle, the screen cloth forming the belt member. It passes over two drums, or pulleys, oversize being discharged while the belt travels under the drums.

Callow Cone.—This is a conical settling tank with vertical central feed, peripheral overflow, annular launder to collect and convey away the overflow, and a spigot in the form of a gooseneck to discharge the tailings.

CALLOW CONE TEST ON BUTTE COPPER SLIMES

	Total gal. per min.	Grams per gal.	Tons per 24 hr.	Assay per cent. Cu	Oz. Ag per ton
Feed...........	1792.7	41.15	117.16	2.80	2.81
Overflow.......	1495.0	16.25	38.45	1.815	2.36
Spigot product..	297.5	154.5	73.13	3.5	3.34

Dehne Filter Press.—One of the best known of the standard plate-and-frame presses, which see.

Dorr Agitator.—An agitating machine based on the thickener

principle. It is essentially a DORR thickener equipped with a central air-lift.

Dorr Classifier.—A machine to diminish the amount of water required for classification by raking the heavier grains up an inclined plane against a light current of water, which washes away the lighter material. It is of the intermittent type.

Esperanza Classifier.—A classifier of the free-settling type in which the settled material is removed by dragging it up an inclined plane by means of a continuous belt of flat blades or paddles. This is continuous in its operation.

France Screen.—A traveling belt screen in which the screen-cloth is mounted on a series of separate pallets, thus avoiding bending the screen as it goes over the pulleys.

Hunt Continuous Filter.—A horizontally revolving continuous vacuum filter. It consists of an annular filter bed, usually of triangular wooden slats filled with coarse sands. The vacuum withdraws part of the pulp moisture as soon as the bed is formed. A spray then washes it after which the vacuum dries it and the material is then scraped off.

Impact Screen.—A type in which the screen moves with the load of material, bringing up against a stop so as to throw the material forward on it. The Imperial is probably the best known type.

Imperial Screen.—A pulsating screen in which the ore is thrown up in the air as well as moved forward over the screen.

Kelly Filter.—This is an intermittent, movable pressure filter. The leaves are vertical and are set parallel to the axis of the tank. Pulp is introduced into the tank (a boiler-like affair) under pressure and the cake formed. The head then is unlocked and the leaves run out of the tank chamber, by means of a small track, and the cake is dropped. The carriage and leaves are then run back into the tank and the cycle begun again.

King Screen.—A drum-type screen in which the pulp to be screened is delivered on the outside, the undersize passing through the screen and discharging through the open end.

Maxton Screen.—A screening machine of the trommel class, open at each end and rotating on rollers supporting the tube through tires at each end. There are radial elevating ribs, to prevent wear of screen cloth and to elevate the oversize. Unscreened material is delivered on the inside screen surface, undersize passing through and oversize being elevated and discharged into a separate launder.

Merrill Filter Press.—A variation of the plate-and-frame press.

Moore Filter Press.—The best known of the movable, intermittent vacuum filters. A series, "or basket," of leaves is fastened together in such a way that it may be dropped in a pulp tank and kept submerged until a cake is formed. It is then transferred by crane to an adjoining wash-solution tank and washed. The basket is then lifted out of this and the cake dropped.

Newaygo.—A slanting screen down which the material to be

screened passes. The screen is kept in vibration by the impact of a vast number of small hammers.

Oliver Continuous Filter.—This consists of a revolving drum prepared as a leaf-filtering surface and divided into compartments, each of which is connected to a vacuum pipe and to a pipe for admitting compressed air. The drum is partly immersed in a tank or box of thick pulp and revolves at a slow rate of speed. The vacuum causes a ¼ to ½-in. slime cake to form; after emerging, the solution is sucked out of the adhering cake; a wash is then given and displaced by air as far as possible; and finally the cake is dropped by compressed air.

Ovoca Classifier.—A classifier of the free-settling type in which the heavy material is removed by a double-screw, continuous-flight conveyor, working up an inclined plane.

Pachuca Tank.—Same as the BROWN tank.

Paddle-wheel Agitator.—The simplest form, in which the solids are kept in suspension by paddles. It is difficult to do with sand, the machine being difficult (if not impossible) to start if sand packs around the blades, and it is expensive both in operating and in repair costs.

Parral Agitator.—An agitator using a number of small air lifts disposed about a circular, flat-bottomed tank in such a way as to impart a circular swirling motion to the pulp.

Patterson Agitator.—An agitator of the PACHUCA-tank type in which the air is replaced by solution or water, under pressure from a centrifugal pump.

Plate-and-frame Filter Press.—The old style press. It consists of plates with a girdiron surface alternating with hollow frames, all of which are held by means of lugs, on the press framework. The corners of both frames and plates are cored to make continuous passages for pulp and solution. The filter cloth is placed over the plates. The pulp passageway connects with the large square opening in the frame; the solution passageways with the girdiron surface of the plate. The DEHNE and the MERRILL are well-known types.

Richard's Pulsator Classifier.—A classifier operating by a pulsating current of water without a screen. The pulp grains fall through a sorting column against an upward pulsating current of water.

Ridgeway Filter.—This is a horizontal revolving, continous vacuum filter. The surface is an annular ring consisting of separate trays with vacuum and compressed air attachments. The filtering surface is on the under side, the trays being dipped into the tank of pulp to form the cake, and then lifted out of it.

Richard's Shallow-pocket Hindered-settling Classifier.—A series of pockets through which successively weaker streams of water are directed upward. The material that can settle does so and is drawn off through spigots.

Sherman Settler.—A series of cylindrical tanks with conical bottoms having central feed and a peripheral overflow. The tanks continually decrease in depth and increase in diameter.

Trent Agitator.—This agitator has the arms of the paddle-

wheel type, but they are hollow, and pulp solution or air is discharged from nozzles on these arms, thus causing the stirrer to rotate.

Trommel.—A revolving screen set at an angle. The material to be screened is delivered inside the trommel at one end. The fine material drops through the holes; the coarse is delivered at the other end.

Vibracone.—A vibrating screen manufactured by the Stephens-Adamson company, in which the feed is from a saucer-shaped distributor onto a conical surface kept in vibration by a ratchet motion.

Power Used in Concentrating Mills

As an indication of what power may be needed in milling, the following table is taken from R. H. RICHARD's "Ore Dressing," Vol. IV, page 1929. The figures are those for the Cananea Consolidated Copper Co.'s No. 2 and No. 1 mills:

	Horsepower
20 trommels 4×5 ft. and 4×8 ft.	20
4 16-in. elevators, 46 ft. between pulley centers	10
4 sets 16×36-in. rolls at 80 r.p.m.	20
6 one-compartment bull jigs (4 active)	8
16 two-compartment middle jigs	16
16 three-compartment sand jigs	16
2 dewatering trommels	1
2 chip trommels	1
10 shovel wheels with shafting	3
2 centrifugal pumps, 1200 gal. per minute, 40-ft. lift	60
8 5-ft. Bryan mills	144
38 Wilfley tables with line shafting	25
36 6-ft. Frue vanners with line shafting	8
2 centrifugal pumps	25
6 shaking launders	3
2 middling elevators	5
2 pulp elevators	3
Friction of engine and remaining shafting	80
Total on mill engine	472

1400 tons of ore treated per day.

	Horsepower
24 trommels	12
2 No. 1 elevators	13
2 No. 2 elevators	14
2 No. 3 elevators	8
2 No. 4 elevators	8
8 bull-jigs (4 active)	8
16 two-compartment jigs	16
8 three-compartment jigs	8
2 Bryan mills	36
2 No. 1 centrifugal pumps	40
2 shaking launders and 2 shovel wheels	2
2 16×36-in. Davis rolls	22
4 14×27-in. Davis rolls	40
shafting and belts	40
engine and jackshaft friction	50
Total engine load	317
42 Wilfley tables	26
36 six-foot Frue vanners	8
2 10×48-in. sand pumps	3
1 No. 2 centrifugal pump	15
Friction of transmission	13
Total motor-driven load	65
Total power required in mill	382

1400 tons of ore treated per day.

Power Used in Boston & Montana Concentrator

Machine	R.p.m.	Horsepower required
Hancock jig	62	3.41
Evans jig	190	0.50
Trommel (3×6-ft.)	....	0.30
Overstrom table	251	0.364
Wilfley table	251	0.352
Vanner (4-ft.)	182	0.230

Water Used in Mills[1]

Mill	Water used per 24 hr., gal.	Capacity of mill per 24 hr., tons	Water used per ton, gal. (c)	Remarks, stamps
	Gold Stamp Mills			
Hector Mining Co., Telluride, Colo.	51,840(a)	90	576.0	30
Franklin Mining, Placerville, Calif.	96,336(a)	60	1,605.6	10
North Star, Grass Valley, Calif.	156,193(a)	64	2,440.5	40
Empire Mill, Grass Valley, Calif.	240,750(a)	60	4,012.5	40
Idlewild Mill, Greenwood, Calif.	239,040(a)	115 to 128	1,867.5 to 2,078.6	40
Grand Victory, Placerville, Calif.	259,600(a)	100 to 150	1,730.6 to 2,596.0	50
Wildman, Sutter Creek, Calif.	151,000(a)	93	1,623.7	30
Madison, Angels Camp, Calif.	123,840(a)	200	619.2	40
West Waverley, Waverley, N. S.	216,000	50 to 65	3,324.6 to 4,320.0	20
Montana, Marysville, Mont.	213,120	105	2,029.7	60
Utica, Angels Camp, Calif.	185,760(a)	300	619.2	60
Stickles Mill, Angels Camp, Calif.	185,760(a)	300	619.2	60
Zeile Mining Co., Jackson, Calif.	179,676(a)	150	1,197.8	40
	Combination Silver Mills			
Montana, Marysville, Mont.	252,576	110	2,296.1	50
Eureka Hill, Eureka, Utah	Steam power 15,360(b) Concentrating 39,480(b) 54,840(b)	120	457.0	60
Mammoth, Tintic, Utah	Fresh 70,000 Repumped 30,000 100,000	100	1,000.0	40
	Jigging Mills			
Friedensville Zinc, Friedensville, Penn.	62,000(c)	120 to 135	459.3 to 516.7	....

MILLS WITH JIGS, VANNERS AND TABLES

Mill	Water used per 24 hr., gal.	Capacity of mill per 24 hr., tons	Water used per ton, gal. (c)	Remarks, stamps
Old Jordan & Galena, Bingham, Utah	237,600	175	1,357.6	....
Central Lead, Flat River, Mo.	1,152,000	175	6,582.8	....
St. Joseph Lead Co., Bonne Terre, Mo.	2,250,000	900	2,500.0	....
Bullion Beck & Champion, Eureka, Utah.	129,600	200	648.0	....
Smuggler, Aspen, Colo.	900,000(a) (c)	100	9,000.0	....
MONTANA COPPER SULPHIDE MILLS				
Butte & Boston, Butte, Mont.	Flows in 1,000,000 Pumped 1,440,000 Repumped 700,000 3,140,000	500	2,000 2,880 1,400 6,280	....
Colo. Sm. & Ref., Butte, Mont.	1,064,000	275 to 300	3,546.7 to 3,869.0	....
Parrot Silver & Copper, Butte, Mont.	1,200,000 to 1,400,000	300 to 350	4,000	....
LAKE SUPERIOR NATIVE COPPER MILLS WITH STEAM STAMPS				
Calumet & Hecla, Calumet, Mont.	20,000,000	2,080	9,615.4	....
Franklin, Hancock, Mich.	3,744,000(d)	450	8,320.0	....
Osceola, Mich.	12,000,000	1,260	9,523.8	....
Quincy, Hancock, Mich.	12,000,000	1,700 to 1,900	6,315.8 to 7,058.8	....
Tamarack, Houghton, Mich.	10,000,000	1,500	6,666.7	....

(a) The mill is run by water power, and this figure does not include the water used for power. (b) This does not include what is repumped. (c) This is for 10 hours only. (d) This is the water that leaves the mill with the tailings. The amount of water coming to the mill is slightly larger.

[1] The table is from RICHARD's "Ore Dressing," Vol. II, and consequently represents the practice of 15 years ago. For all that, it is a valuable guide to have as to what water may be necessary.

Water Consumption in Various Mills

	Gal. water per 24 hr.	Tons ore per 24 hr.	Water used per ton of ore		Remarks
			Gallons	Tons	
Gold Stamp Mills[3]					
Haile, South Carolina..	360,000	150	2,400	10	60 stamps
Jigging Mills					
Smuggler Mining Co...	2,160,000	400	5,400	22.5	....
St. Joe Lead..........	4,000,000	1,200	3,333	13.9	....
St. Louis Sm. & Ref....	5,760,000	1,800	3,200	13.3	....
Block 10.............	864,000[1]	575	1,500[1]	6.26	....
	69,000		120	0.5	Australian
Daly-West............	504,000[1]	500	1,008[1]	4.2	....
	57,600		144	0.6	....
Minas Tecolotes.......	2,001,600[1]	600	3,336[1]	13.9	....
	338,400		567	2.36	....
Silver Lake...........	1,885,000	325	5,800	24.2	....
Iron Ore Washery[4]					
Oliver Iron...........	300,000[2]	1,000[2]	300	1.25	....
Longdale Iron.........	1,144,800	480	2,385	10.0	....
Montana Copper Sulphide Mills					
Anaconda............	44,352,000	8,800	5,040	21.0	....
Boston & Montana....	25,000,000	3,000	8,300	34.6	....
Utah Copper Sulphide					
Newhouse M. & S.....	1,440,000[1]	1,000	1,440[1]	6.0	....
	720,000		720	3.0	
Utah Copper Co.......	8,640,000	6,000	1,440	6.0	....
Nevada Copper Sulphide					
Giroux Con...........	800,000[1]	800	1,000[1]	4.0[1]	....
	160,000		200	0.83	....
Arizona Copper					
Detroit Copper Min. Co.	275,000	1,100	250	1.04	....
Old Dominion.........	750,000	500	1,500	6.26	....

[1] In mill circulation. [2] Ten hours. [3] According to Richards, the water used in stamping varies from 1 to 6.69 gal. per stamp per minute in the various mills under his observation, and 2.40 to 15.97 tons per ton of ore stamped. South African practice seems to be about 4 to 10 tons of water per ton of ore milled. [4] Log washers take about 2000 gal. of water per ton of ore in Southern practice.

Adjustment, Feed and Capacity of Mill Vanners

Abbreviations.—In. = inches; R. = round holes in stamp screens; Sq. = square holes in stamp screens

Mill number.	Kind of vanner	Belt			Slope		Travel of belt, inches per minute	Number of vibrations per minute	Feed		Tons treated by one vanner in 24 hours
		Kind	Width, feet	Life in months	Inches in 12 ft.	Degrees			Source	Maximum size (a'), mm.	
18	Frue	Frue	4	....	6–7⅛	2°25'–2°50'	65½	205–210	(e)	....	....
19	Frue	(b')	4	....	....	....	....	....	(e)	....	....
20	Frue	Frue	......	24–36	5	2° 0'	....	190	(r)	....	....
24	Frue	Frue	4	12	....	....	....	190	(t)	....	....
26	Frue	Blaisdell	6	24–60	2	0° 50'	24–36	196	(c)	....	4–6
	Johnston		6		3	1° 12'	55	116	(r)	....	4–6
	Woodbury (g')	Woodbury	5	....	4.4 6.1	1° 45' 2° 25'		230	(b)	....	....
27	Woodbury (g')	Woodbury	5	....	1½ 1.9	0° 35' 0° 45'	80 76	230	(w)	....	....
	Woodbury (g')	Woodbury	5	....	3.4 3.8	1° 20' 1° 30'	80 85	230	(k)	....	....
30	Frue	(b')	......	....	....	....	....	....	(w)	....	....
31	Frue	Blaisdell (b')	4	....	4	1° 35'	26	200	(l)	....	....
32	Frue	(b')	4 & 6	....	3	1° 12'	36	200	(f)	....	....
34	Frue	(b')	4	....	....	....	....	190	(w)	....	....
35	Frue	....	4	48	1½	0° 35'	(d')24	215	(e)	....	....
36	Frue	(b')	4	....	....	....	....	....	(m) or (w)	....	....
	Frue	(b')	4	....	....	....	....	....	(o)	....	....
37	Frue	....	6	....	....	....	....	....	(p)	....	....
38	Frue	Frue	4	54–60	3⅓	1° 20'	35–41	190–194	(w)	....	....
39	Frue	....	4	....	1¼ 4.6	0° 35' 0° 50'	46 51	186	(g) (i)	....	....
40	Frue	(b')	4	60	3	1° 12'	36–48	204	(e)	....	....

41	Frue	....	4								
	Tulloch	Canvas Rubber	5	6 48	....	....	....	....	(r)	....	....
	Embrey	....	4	....							
43	Frue	(b′)	4	....	3½	1° 25′	36–72	200	(w)(y)(f)	....	....
53	Frue	Frue	4	....	3½	1° 25′	48	160	(a)	0.70 Sq.	7½
	Woodbury (g′)	Woodbury	5	....	3½	1° 25′	48	235			
54	Frue	Blaisdell (b′)	6	....	4	1° 35′	35	200	(a)	....	16⅔
	Frue	....	6	....	3	1° 12′	20	200	(z)	....	8⅓
55	Frue	Smooth surface	4	....	4	1° 35′	30	200	(a)	1.10 Sq.	4⅓
	Triumph										
57	Triumph	Blaisdell (c′)	4	(e′)	3	1° 12′	26	230	(a)	0.79 R.	4
	Frue	Blaisdell (c′)	4		2¼	0° 54′	24	200			
58	Frue	Frue	4	120	2.3–2¾	0°55′–1°5′	28	200	(a)	0.59 Sq.	5
	Triumph	Blaisdell (c′)	5	....	5¼	2° 5′	42–46	238			
59	Triumph	Triumph Brownell Woodbury	4	24–30 36	3	1° 12′	26	200	(a)	0.64 R.	3¾
60	Frue	Blaisdell (c′) Blaisdell (c′) Woodbury	4	30	3¾ 5⅞	1° 30′ 2° 20′	45 60	....	(a)	....	4¼
61	Woodbury (g′) Woodbury (h′)	Woodbury	5	30	8.8	3° 30′	72	225	(a)	0.81 R.	15
62	Frue	Blaisdell (b′)	4	....	3¾	1° 30′	45	206	(a)	0.75 R.	7½–10½
	Triumph	Blaisdell (b′)	5	....	5.4	2° 10′	48	220			
63	Frue	Frue	4	....	5⅔	2° 15′	31	180	(a)		5
64	Frue	(b′)	4	48	3–5	1°12′–2°0′	36–72	190	(a)	....	7¾
	Triumph	(b′)	4	48	2½	1° 0′	36–48	230			
65	Frue	Blaisdell (b′)	4	....	5¼	2° 5′	30.6	168	(a)	0.76 R.	12½
	Union	Blaisdell (b′)	4	....	6½	2° 35′	36	171			
68	Frue	Frue	4	....	3.6	1° 25′	22	196	(a)	0.52 Sq.	4.4
69	Frue	Frue	6	....	....	....	....	....	(a)	....	6⅔
71	Frue	Frue	4	....	3⅓ 4.2	1° 20′ 1° 40′	55 63	216 206	(a)	....	4
72	Woodbury (g′)	Woodbury	5	....	3½	1° 25′	50	220	(a) (d)	....	12
73	Frue	Loring Frue Brownell Blaisdell	4	72	4½–5¼	1° 47′–2° 5′	32–35	175–185	(a)	0.76 R.	12½

ADJUSTMENT, FEED AND CAPACITY OF MILL VANNERS. *Continued*

Mill number	Kind of vanner	Belt			Slope		Travel of belt, inches per minute	Number of vibrations per minute	Feed		Tons treated by one vanner in 24 hours
		Kind	Width, feet	Life in months	Inches in 12 ft.	Degrees			Source	Maximum size (a'), mm.	
74	Tulloch	Blaisdell (c')	3 10/12	....	6½	2° 35'	55	150	(a)	0.76 R.	12½
	Frue	Blaisdell (c')	4	....	5¼	2° 5'	38	186			
75	Frue	....	4	60	4½	1° 47'	37–42	188	(a)	1.13 Sq.	9¾
76	Frue	(b')	6	....	....	....	....	....	(v)	....	7½–12½
78	Gates	(b')	4	....	18	7° 7'	85	224–240	(x)	....	....
79	Woodbury	Woodbury	....	....	....	....	....	....	(x)	....	....
82	Frue	Frue	4	60	3	1° 12'	38	190	(a)	0.52 Sq.	5½
83	Frue	Blaisdell (b')	6	....	3	1° 12'	24–36	200	(a)	0.42 Sq.	10
	Frue	Blaisdell (b')	6	....	3	1° 12'	20–30	200	(z) (a)	0.42 Sq.	7½
84	Frue	Blaisdell (b')	6	....	4	1° 35'	35	200	(a)	0.41 Sq.	12½
	Frue	Blaisdell (b')	6	....	3	1° 12'	18	200	(z)	0.41 Sq.	5¾–6
86	Frue	....	4	....	....	....	....	....	(s)	....	....
87	Woodbury (g')	Woodbury	5	....	2⅓–7	0°55'–2°45'	....	200	(r)	....	....
88	Woodbury (g')	Woodbury	5	....	4.2	1° 40'	80	223	(r)	....	....

[1] From R. H. RICHARD'S "Ore Dressing." The mill numbers refer to this book.

(a) Gravity stamps. (b) HUNTINGTON mill. (c) BRYAN mill. (d) GRIFFIN mill. (e) Spigots of whole current classifier. (f) Separate spigots of whole current classifier. (g) Spigots of No. 1 whole current classifier. (i) Spigots of No. 2 whole current classifier. (k) Spigot of whole current classifier mixed with finest jig tailings. (l) Overflow of No. 2 whole current classifier mixed with slime-table middlings. (m) First spigot of surface current classifier. (o) Second spigot of surface current classifier. (p) Second spigot of box classifier. (r) Overflow of hydraulic classifier. (s) Spigot of No. 2 hydraulic classifier. (t) Settlings from settling tank. (v) Carpet-table tailings. (w) Slime-table middlings. (x) Canvas-table heads. (y) Tailings of finest jig. (z) Preceding vanners. (a') These figures are the diameters of holes in the gravity-stamp screens when new. As the screens wear the size of particles will increase slightly. (b') Smooth surface. (c') Corrugated surface. (d') More or less. (e') Some more than 9 years, some less. (g') With seven belts. (h') With thirteen belts.

Canvas, Blanket and Carpet Tables

Kind of table	Length		Width		Slope		Life of surface	Feed	Destination of		Tons treated per table in 24 hr.
	Ft.	In.	Ft.	In.	In. per ft.	Degrees			Concentrates	Tailings	
Brussels carpet....	3	0	(*v*) 4	8	2¼	10° 35′	....	(*a*)	(*i*)	(*r*)	10–15
Canvas...........	10	0	12	0	1¼	5° 55′	....	(*b*)	.....	.....	....
Brussels carpet....	16	0	(*v*) 4	8	(*h*) 2	9° 30′	....	(*a*)	(*i*)	(*r*)	7.5–12.5
Wool blanket......	3	6	1	8	2	9° 30′	12 months	(*a*)	(*k*)	(*r*)	5⅔
No. 6 cotton duck..	10	0	12	0	1½	7° 5′	8 months	(*b*)	(*m*)	(*s*)	1.25
No. 6 cotton duck	10	0	12	0	1⅛	5° 20′	8 months	(*c*)	(*m*)	(*s*)	....
No. 6 cotton duck..	10	0	12	0	....	....	8 months	(*d*)	(*m*)	(*s*)	....
No. 4 cotton duck..	39	6	1	8	7/10	3° 20′	....	(*e*)	(*m*)	(*s*)	1.9
No. 4 cotton duck..	16	6	1	8	¾	3° 25′	....	(*f*)	(*m*)	(*s*)	....
No. 8 cotton duck..	42	0	1	8	1⅛	5° 20′	10 months	(*g*)	(*o*)	(*t*)	4.55

(*a*) Stamp pulp from amalgamated plates. (*b*) Overflow of hydraulic classifier. (*c*) Overflow of box classifier. (*d*) Tailings of special vanner. (*e*) Coarse riffle-box tailings. (*f*) Fine riffle-box tailings. (*g*) Vanner tailings. (*h*) Approximately. (*i*) Cleanup barrel. (*k*) Smeltery. (*m*) Special vanner. (*o*) Cyanide leaching. (*r*) Vanners. (*s*) Waste. (*t*) Arrastre. (*v*) Partitioned down the center.

Water Used in Jigging

According to RICHARDS, a jig will use anywhere from 0.528 to 22.22 gal. of water per square foot of jig area per minute, and from 8.76 to 54.98 tons of water per ton of ore in American practice, and 1.23 to 33.04 tons of water per ton of ore in European practice. The stroke of a jig varies from 1.63 to 7.18 times the diameter of the average grain fed to it. The coarser the grains the greater should be the throw, because coarse grains settle faster than fine grains and require a higher velocity of current and a greater quantity of water to lift them. The heavier the grains, the greater should be the stroke.

CARKEEK'S SLOPE FOR LAUNDERS[1]

Size of ore	Degrees	Slopes, inches per foot	
Mine ore to breaker	36° 35′	8.9	Dry.
2 in. to 1 in	37° 50′	9.33	Wet.
1 in. to ½ in	33° 40′	8.0	Wet.
½ in to ¼ in	29° 5′	6.66	Wet.
¼ in. to ⅛ in	24° 0′	5.33	Wet.
⅛ in. to 1/16 in	18° 25′	4.0	Wet.
1/16 in. to vanner material	7° 33′	1.6	Wet.
Table or vanner material	6° 20′	1.33	Wet.
Tail race for 1/16-in. material	3° 35′	0.75	Wet.
Tail race for ⅛-in. or larger	6° 20′	1.33	Wet.
Trommel casing for − ½-in. material	16° 15′	3.5	Wet.
Trommel casing for + ½-in. material	33° 40′	8.0	Wet.

[1] R. H. RICHARDS, "Ore Dressing," Vol. II.

Quantities of Water Flowing in Rectangular Launders of Rough Plank

Depth of water in inches	Slope in 1 ft.				
	1/8 in.	1/4 in.	1/2 in.	1 in.	2 in.
	Gallons per Minute, Launders 4 In. Wide				
1/2	5.8	8.2	11.7	16.5	23.3
1	18.9	26.3	37.8	53.5	75.7
2	52.4	74.2	105.0	148.0	210.0
3	91.6	130.0	183.0	259.0	366.0
4	129.0	183.0	259.0	366.0	517.0
	Launders 8 In. Wide				
1	42.1	59.5	84.2	119	168
2	129.0	189.0	259.0	366	517
3	240.0	339.0	479.0	676	958
4	363.0	519.0	726.0	1,027	1,452
6	625.0	884.0	1,250.0	1,767	2,500
8	890.0	1,253.0	1,779.0	2,516	3,558
	Launders 12 In. Wide				
1	69.3	98	139	196	277
2	211.0	298	422	597	844
4	625.0	884	1,250	1,767	2,500
6	1099.0	1,554	2,198	3,108	4,396
9	1908.0	2,698	3,816	5,395	7,631
12	2736.0	3,868	5,471	7,736	10,943
	Launders 16 In. Wide				
1	94	133	188	266	376
2	309	437	617	873	1,235
4	890	1,258	1,779	2,516	3,559
8	2,432	3,438	4,863	6,877	9,727
12	4,116	5,820	8,232	11,640	16,464
16	6,000	8,485	12,001	16,961	24,002
	Launders 32 In. Wide				
1	196	278	393	556	786
2	650	919	1,301	1,839	2,601
4	2,075	2,933	4,149	5,167	8,298
8	8,000	8,435	12,001	16,969	24,002
16	16,023	22,657	32,046	45,313	64,092
24	26,751	37,826	53,503	75,653	107,005
32	38,590	54,565	77,179	109,131	154,358

Speed of Current Necessary to Move Different Sizes of Sand and Pebbles[1]

Material	Velocities at bottom of stream. feet per second	
	Slowest observed velocity that moved the grains	Fastest observed velocity that did not move grains
Brown clay (sp. gr. 2.64)	0.36	0.27
Fine sand (sp. gr. 2.64)	0.62	0.53
Coarse sand	1.07	0.71
Gravel, size of anise seed	0.53	0.36
Gravel, size of peas or larger	0.71	0.62
Gravel, size of common beans	1.55	1.07
Beach pebbles, 1 in. or more	3.20	2.13
Angular weather flint, egg size	4.00	3.20

Percentages of Moisture Retained by Different Sizes of Ore After Thorough Wetting Followed by Reasonable Draining

Size, mm.	Material	Moisture, per cent.[1]	Size, mm.	Material	Moisture, per cent.[2]
64–32	Ore	0.35	4–3	Ore	5.66
32–22	Ore	0.55		Calcite	5.21
22–16	Ore	0.74	3–2	Ore	6.19
				Calcite	6.06
16–12	Ore	1.33	2–1	Ore	8.59
	Calcite	2.49		Calcite	9.30
			1–0.5	Ore	17.59
12– 8	Ore	2.25		Calcite	18.90
	Calcite	2.58	0.5–0.35	Ore	18.16
8– 6	Ore	3.01		Calcite	20.44
	Calcite	3.38	0.35–0.10	Ore	16.80
6– 4	Ore	2.91		Calcite	20.57
	Calcite	3.91	0.10–0	Ore	16.94
				Calcite	21.69

[1] R. H. Richards, "Ore Dressing," Vol. II.
[2] Percentage calculated on weight of mixture of pulp and water.

'EED OF MINERAL GRAINS FALLING IN WATER (METERS PER SECOND)[1]

)iameter in mm.	Nature of grains	1/8 sec.	1/4 sec.	1/2 sec.	1 sec.	2 sec.
15	Galena	0.903	1.441	1.630	1.650	1.650
	Pyrites	0.825	1.174	1.287	1.293	1.293
	Quartz	0.570	0.767	0.801	0.817	0.817
4	Galena	0.704	0.814	0.823	0.824	0.824
	Pyrites	0.586	0.643	0.646	0.646	0.646
	Quartz	0.383	0.409	0.409	0.409	0.409
1	Galena	0.409	0.413	0.414	0.414	0.414
	Pyrites	0.321	0.323	0.323	0.323	0.323
	Quartz	0.203	0.204	0.204	0.204	0.204

SLOPE OF PLATES IN AUSTRALIAN MILLS[2]

Name of mill	Situation	Slope of plates, inches per foot	Water per battery per minute, gallons
ew Star of the East	Ballarat	7/8	37 1/2
ld Star of the East	Ballarat	3/4	37 1/2
ritannia United	Ballarat	1	25
arrietville	Ovens district	7/8	25
riental	Ovens district	3/4	20
ld Fortuna	Bendigo	1 5/16	....
ew Fortuna	Bendigo	1 1/8	....
earl	Bendigo	1 3/4	32 1/2
ew Chum Consolidated	Bendigo	1 1/4	....

The Flotation Process[3]

Everybody has, of course, noticed the dearth of discussion oout the flotation process in the current technical literature. he explanation of this is the still unsettled patent litigation id the attitude of Minerals Separation, Ltd., the claimant. nat company will neither permit its own employees to talk write about the process, nor will it permit the employees of s licensees to do so. We do not recollect any metallurgical ocess of broad application and use respecting which such forts toward secrecy have been exerted and so far have been ccessfully maintained. Toward that end no stone is left iturned. For example, a flotation apparatus is introduced

[1] "Handbook of Milling Details," McGraw-Hill Co.
[2] R. H. RICHARDS, "Ore Dressing," Vol. II.
[3] *The Engineering and Mining Journal*, Jan. 30, 1915.

somewhere for experimental purposes. The experiments finished, the apparatus, which is essentially a construction of timber, is destroyed with axes. Naturally those concerns which are employing the flotation process without license from Minerals Separation and are liable to be called into court, keep their mouths shut as a matter of policy.

This situation is likely to prevail until a final decision in the Hyde case is rendered by the Supreme Court of the United States. In the meanwhile the suit against the Miami Copper Co. has been taken under advisement and a decision is expected this Spring (1916). This suit brought into court review the Callow and the Towne systems of flotation.

The flotation process as practised is a matter of delicate adjustment. With any given ore experiments may fail to give any promise whatever, simply because of failure to conform to some essential, and usually simple, condition. The size of the ore, the quantity of the feed, the temperature, etc., must all be just right, and especially must regularity of feed be attended to carefully. The fundamental features of the treatment also vary according to different ores. Thus, in floating the blende of Butte the addition of acid is necessary. In floating the copper ore of Miami the presence of acid is fatal. The character of the oil used also varies according to the ore. In the treatment of the zinc-lead ores of Broken Hill eucalyptus oil is commonly employed. In the treatment of the zinc ores of Butte, pine oil, a product of wood distillation (analogous to the eucalyptus oil of Australia) is generally used. Sometimes a little oleic acid is added. In the flotation of copper minerals heavier mineral oils are used. The choice seems to be more or less dependent upon what it is desired to accomplish. In the concentration of copper ore the aim is to extract all the copper possible and if considerable gangue is dragged out with it, no great harm is done. In the concentration of blende, however, the production of a high grade of concentrates is more important than the extraction of the maximum possible percentage of zinc. Therefore a lighter, more delicate oil is favored. In some processes of selective flotation some oils that are very light indeed are used. We have touched upon a few of the important points in connection with this process that ought to be discussed in technical literature, but probably that is not to be expected so long as the shadow of the litigation is over us.

Flotation Processes[1]

Crilley and Everson.—The ore is crushed to 50 mesh, and mixed with a thick black oil. Boiling water containing enough acid to give it a tart taste is then added. This process was tried at Baker City, Ore., and at Denver, in 1889.

Robson and Crowder.—The ore was mixed with but little water, 25 to 30 per cent., agitated and oil added during agitation. This was operated at the Glasdir mine in Wales, in 1894.

[1] From Hoover's "Concentrating Ores by Flotation," "*The Mining Magazine*," London.

Elmore (Old Process).—The ore was mixed with several times its weight of water, and an equal, or greater weight of oil in a revolving drum. The oil was mixed without emulsifying, then run on a spitzkasten, where the oil carried the sulphides to the surface, and the gangue and water were removed from the bottom. This process was invented in 1898 and tried extensively. Its history may be said to close in 1905.

Potter-Delprat.—The original POTTER process (1902) was one of flotation in a 1 to 10 per cent. acid solution. The mixture was 1:1 of ore and acid solution; this was agitated freely and heat applied, causing the forming of CO_2 from the carbonates in the ore. This caused the sulphides to rise to the surface where they were either allowed to flow off continuously or were skimmed off. This was clearly a surface tension process. DELPRAT (1902) accomplished the same thing with acid saltcake solution. Both processes were tried out at Broken Hill, Australia. Later patents indicate that oil has been found to assist in this process. These inventors worked independently, became involved in litigation and eventually pooled their interests.

Froment.—ALCIDE FROMENT discovered in 1901 that when a sulphide ore is agitated in water with a little oil and sulphuric acid, the sulphide particles become oiled and attach themselves to and are floated by gas bubbles. He recommended adding a little calcite to the ores when needed. Minerals Separation, Ltd., bought this patent in 1903.

Minerals Separation, Ltd.—Organized in 1903 by BALLOT, CURLE, WEBSTER, GREGORY, SULMAN and PICKARD to acquire the CATTERMOLE patents. Soon after bought the FROMENT patents. Present processes are based on surface-tension phenomena, accelerated by means of addition to the pulp of small quantities of oil and air in minute subdivision. There is only about 0.1 per cent. oil added, and very violent agitation is indulged in for from 1 to 10 minutes. Innumerable small bubbles of air are thus mechanically introduced which join the oil-coated particles. These are then removed on a spitzkasten. Exposure to air after this treatment then aërates any mineral which has not already taken up its oil film after which a second spitzkasten treatment removes this.

Cattermole.—Added 4 to 6 per cent. of oil, according to the sulphide contents, to a freely flowing pulp, and also 2 per cent. of soap. This process was bought up by Minerals Separation, Ltd.

Goyder and Laughton.—Their process (1905) was only a variation of the POTTER-DELPRAT. It was used at Broken Hill.

Wolf.—JACOB D. WOLF in 1903 invented a method of applying the principles of flotation. He used sulpho-chlorinated or other oils and aimed to secure a high extraction with a low grade of concentrate in the first step, and by washing with hot water to concentrate the concentrate in a second step. Apparently no commercial use was made of it.

Elmore (Vacuum Process).—In 1904 FRANCIS E. ELMORE took out patents covering a process in which flotation is secured by the addition of a small quantity of oil, and by the liberation of air in the pulp in a finely divided condition, this being accomplished by subjecting the freely flowing pulp to a vacuum and simultaneous heating.

De Bavay.—AUGUSTE J. F. DE BAVAY in 1904 invented a flotation process in which a freely flowing pulp was brought to the surface of a vessel of water, where advantage was taken of the surface tension of the liquid, and the sulphide floated. A film of carbonate on the sulphide, from weathering, is detrimental, and is removed by soaking the ore in a weak solution of carbonate of ammonia, or by passing carbon dioxide through the pulverized wet ore, or by friction. In the original process no oil or acid was used. Later these were also made use of.

Macquisten.—ARTHUR P. S. MACQUISTEN, in 1904, invented a process and a tube apparatus for floating sulphides by surface tension. Oil has since been added to the process. It is operating at the Morning mill at Mullan, Idaho.

Zinc Corporation.—Organized in 1905 to treat zinc tailing in the Broken Hill district. Tried POTTER process in 1905. Remodeled plant in 1907 for Minerals Separation process. In late 1907 and 1908 built an ELMORE vacuum mill. In 1910 again adopted Minerals Separation.

Hyde.—In 1911 JAMES M. HYDE patented a process in which a small amount of sulphuric acid, with or without the use of copperas, is used to give the slimy portion of the ore a preliminary coagulation before flotation. The sulphides, after agitation, are floated off rapidly and as completely as possible with a considerable overflow of freely flowing water, thereby producing an impure concentrate which is re-treated in a second machine. At present the process is being used by the Butte & Superior Copper Co., and is in litigation with Minerals Separation, Ltd.

Murex.—While this process is not strictly of the same class as the others, it still makes use of the principle of selective oiling of sulphide particles. In this process the crushed ore is fed into an agitator and mixed with 4 to 5 per cent. of its weight of a paste made of 1 part of oil or thin tar with 3 or 4 parts of magnetic oxide of iron. This oxide must be ground to an impalpable powder. These ingredients, with enough water to make a pulp, are agitated from 5 to 20 minutes. The paste preferentially adheres to the sulphides because of the oil. The ore is then fed over magnets and the oxide of iron, with the mineral adhering to it, pulled out. The oil and magnetite are then recovered.

Sanders.—This process uses, instead of an acid bath in deep pans, a dilute solution of aluminum sulphate in shallow pans. It was tried by the Tri-Bullion Smelting & Development Co. on a commercial scale, without success.

Horwood.—If a mixture of iron, copper, lead and zinc sulphides is roasted, the three former can be changed to oxide and

sulphide at a comparatively low temperature, whereas the blende is practically unaltered. The partly roasted material is then subjected to a heated-acid oil-flotation process, by which the zinc is floated, the other metals staying behind.

Air in Ore Available for Elmore Process[1]

Proportion of water to ore	Cu. ft. of available air in this water	Lb. of sulphide this will float	Percentage of mineral in the ore
1:1	0.75	60	2.7
2:1	1.50	120	5.4
3:1	2.25	180	8.1
4:1	3.00	240	10.8
5:1	3.75	300	13.5
6:1	4.50	360	16.2
7:1	5.25	420	18.9
8:1	6.00	480	21.6
9:1	6.75	540	24.3
10:1	7.50	600	27.0

As the proportion of water to ore rarely exceeds 6:1, and as the ores usually yield over 16 per cent. of concentrate, it may be seen that some other gas than that naturally found in the water must be found to effect flotation. This is generally secured by adding limestone to the ore, and then acid at the point where the pulp enters the vacuum chamber.

In general, ore must be crushed to at least 40 mesh to obtain the best results in flotation.

Ideal ores for flotation processes are said by Hoover to be as follows:

	Pb	Zn	Fe	Cu	Mn	S	CO_2	SiO_2	CaO	Al_2O_3
Acid flotation.	7	20	8	....	3	14	3	42	1	......
Oil-air........	....	....	12	3	....	....	......	72	......	2

The first is from Broken Hill, the second from Bolivia.

Testing Oils for Flotation[2]

It has long been recognized that a well-equipped experimental testing laboratory is necessary for the successful working of a flotation concentrating plant. Of the many various tests which are required from time to time, the most frequent and perhaps the most important is the testing of oil, or active floating medium. The following remarks refer chiefly to eucalyptus and resinous oils:

The first material necessary is a standard ore sample. For the

[1] T. J. Hoover's "Concentrating Ores by Flotation," "*The Mining Magazine*," London.

[2] Excerpts from an article by J. Coutts, in *Aust. Min. Stand.*, Apr. 8, 1915.

purpose of oil testing, a thoroughly representative sample of the material to be treated is dried, crushed to pass 60 mesh and bagged. For convenience, a supply ready for use may be weighed off in 1-lb. lots and put up in small tins.

A sulphuric-acid solution, containing 405 grams of H_2SO_4 per liter, is generally used, 1 cc. of such a solution containing 2 lb. of pure acid per ton, when working on 1 lb. of ore sample.

A standard oil sample is that oil which has been found to fully meet the requirements of the proposition, upon which all future calculations are based and comparisons made. It may be stored ready for use in bottles.

Preliminary Examination

For specific gravity tests hydrometers reading to 0.001 are required. In all cases it is necessary to ascertain the specific gravity of the oil, with the view, at least, to future calculations. This may be carried out at any suitable temperature which has been fixed upon as standard. It has been found advisable to check the specific gravity of the standard oil simultaneously, because of the gradual increase in specific gravity which takes place owing to the loss of lighter oils by volatilization. A correction for temperature is made by allowing 0.00045 for each deg. Fahrenheit.

A small burette is used for counting the number of drops in 1 cc. of the oil, also for admitting the oil to the machine during testing operations: The greater the number of drops delivered by the burette, the greater the accuracy of the test. To obtain a suitable dropper, cut a burette about 8 in. above the cock, almost close the discharge orifice by dumping up the glass with a blowpipe flame, then grind the outside back to a point so that a minimum surface is presented to the oil drop. The burette should at normal temperatures give between 80 and 90 drops per cubic centimeter, when run at the rate of 1 drop per second. The temperature of the oil during dropping test should correspond with the temperature during flotation test.

Having obtained the number of drops per cubic centimeter and the specific gravity, it is easy to calculate the number of pounds of oil per ton of ore, when working on 1 lb. of sample.

Thus $\dfrac{2240 \times sp.\ gr.}{453.6 \times drops\ per\ cc.} = lb.\ of\ oil\ per\ long\ ton.$

It is sometimes desired in practice to use a mixture of oils. When the oil under examination is to be used in conjunction with other oils, these should be wholly miscible in the proportions in which they are to be used.

The following classification and explanations will serve to give a general idea of the methods employed when carrying out various tests: (1) flotation of lead, zinc and other sulphides, as a mixed concentrate; (2) differential separation, or selective flotation of one sulphide in the presence of other sulphides (the term "differential separation" is usually applied to the selective flotation of lead sulphide from zinc and other sulphides); (3) flotation of copper and iron sulphides.

Outline of Test Process

The testing of oils in the laboratory is carried out by comparing measured quantities (from 3 to 6 drops) of a standard oil, with a similar quantity of the oil under examination, the values being arrived at by comparing the results obtained from each series of tests. Tests are usually made on 1 lb. of standard ore sample in 4 lb. of water at a standard temperature, acidulated with a definite quantity of sulphuric acid. The oil then being admitted, the mixture is agitated in a specially constructed agitating machine, the principle of which is dependent on the object of the test. The float produced is skimmed off, dried, weighed and assayed.

Test 1. The Flotation of Mixed Sulphides.—Almost any eucalyptol oil which produces a persistent froth, and leaves a gummy residue on evaporation, is suitable for this class of work. An agitating machine may be constructed by cutting a packing bottle about 10 in. above the neck (a bell jar of suitable dimensions can be obtained). Fit four copper baffles, $4 \times 1\frac{1}{2}$ in. wide, to a copper band of the same width and push this arrangement hard down into the bottle (the band being first bent to fit the inside circumference of the bottle). The lower ends of the baffles will jam hard to a point where the concave glass begins. The band is then expanded hard against the glass, and held in position by soldering the separated ends. The mouth, or discharge end, is closed with a rubber stopper, through which is passed a glass or metal tube fitted with a short rubber tube and clip. The bottle with the baffles in position is inverted and clamped centrally under two pairs of suitable bearings, which carry a ½-in. impeller shaft. At the upper end of the shaft is fitted a driving wheel, and at the lower end a four-bladed impeller which just has clearance between the lower points of the baffles and the glass. The blades of the impeller have a lateral angle of about 45° and should be driven at about 1200 r.p.m. in a lifting direction.

Test 2. Differential Separation.—For differential separation, an oil high in phlanderene which leaves a gummy residue on evaporation is used. Phlanderene may be tested for by a polariscope. Differential separation is worked in acid and neutral and in hot and cold liquors, and being still in its infancy, allows of many types of machines and schemes. Each different ore requires some modifications, but the principal in main is the addition of medium and aëration from below, which is effected by air jets or suction created by the impeller.

Test 3. Flotation of Copper and Iron Sulphides.—An oil which gives a deflection by the polariscope of 60 or over is considered sufficiently high in phlanderene for use in copper flotation. Tests are usually made with the apparatus described in Test 1, using cold circuit liquors made slightly acid. In practice the mine water usually contains sufficient acid for the purpose.

RECENT PROGRESS IN FLOTATION[1]

Certain progress in the more general details of flotation milling is of interest. For instance, it now looks as if much of the older concentrating machinery is going to be displaced by flotation machinery. The first application of flotation was to retreat slimes carrying valuable sulphides, and it was hence merely an addition to slime-treating machinery, such as vanners and slime tables. Soon the vanner heads instead of the tails were being tested in the flotation machines, and the results have varied greatly. In some places the flotation machines are still treating the vanner or slime-table tails; in others the tests have shown better work with the older slime-treating machinery entirely eliminated. Of course, the criterion used has been the economy of concentrating the various ores in question.

Although slime-treating machinery could now be almost entirely dispensed with, there is still some doubt in many cases as to the advisability of doing so. However, some men have gone much farther and have suggested that it may be advisable to displace the sand-concentrating tables and to grind all material for direct treatment by flotation. In fact, one large copper company has decided to displace all concentrating machinery with the exception of rougher tables and regrind the tails from these for flotation. But with, say, a lead- or a zinc-sulphide ore containing the valuable minerals in large clean crystals it is hard to see why such a practice should be necessary. It would seem that only the fines and slimes, which are inevitably produced by any crushing, should require flotation treatment. This, of course, leaves out of consideration the cases where heavy gangue minerals make mechanical concentration of other kinds difficult.

"Cleaning" Flotation Products

The practice of "cleaning" both flotation concentrates and tails is another development, at least in American practice.

Only a few years ago "rougher" and "cleaner" units were not commonly spoken of. Now almost every installation, of whatever type, is retreating the concentrates from a "rougher" machine in a "cleaner" machine in order to drop out most of the gangue material and some of the middlings which need further treatment. Moreover, it is becoming customary to add suitable oils to the tailings for further flotation treatment in order to produce clean tailings and a low-grade middling product. These various middling products are reground in the best practice and returned to the circuit, while in other instances simple return of middlings without regrinding is common. Another point of interest has been the installation of all manner of "drag" devices for removing any froth that may form on the pulp in the subsequent handling of tailings, such as in dewatering or thickening. It is also a debated question as to whether

[1] Excerpts from an article by O. C. Ralston and F. Cameron, *Eng. and Min. Journ.*, May 29, 1915.

further flotation treatment before discharge is not better practice.

Another development when using pneumatic cells of the CALLOW type has been to add "recleaners" for further treatment of the concentrates from the froth "cleaners." Thus we have "roughing" machines followed by "cleaners" for the tailings, and, in some installations of the CALLOW type "cleaners" and "recleaners" for the concentrates. As a matter of fact, the same general sequence of treatment is followed in the many compartments or cells, in series, of the Minerals Separation type of machine.

Breaking Up the Froth

The further handling of froth concentrates has proved a serious problem for many operators when the froth has been tough and permanent. The most common method of breaking froth is by jets or sprays of water. A single strong jet of water turned on the flowing froth in a launder often results in material benefit, and a water pipe perforated with many holes to give more jets is better, while special sprays, such as rotating garden sprays (inverted), Buffalo sprays, etc., prove even more efficient. Direct feed into a filter of the pressure-filter type is most efficient, as the froth does not need to be broken up. The vacuum filters are not so well adapted to immediate treatment of the froth because it generally is too thin (25 per cent. to 35 per cent. solids) to cake well; vacuum filters of the Portland or OLIVER type require approximately 50 per cent. solids in the pulp. However, by breaking the froth and dewatering, a vacuum filter is permissible. In a number of installations a bucket elevator seems to break up the froth to a satisfactory extent, actual tests made by one company indicating 80 per cent. efficiency in breaking froth, merely in the passage of the froth through the bucket elevator. Addition of chemicals, such as acid or lime, or of more oil to the froth, also tends to break it down and make the solids settle out well. If lime be used for this purpose, the mill water cannot be used again without neutralizing.

Settling of froth in bins for dewatering, while a common practice, is not satisfactory, as it practically imposes a canvas lining for the car in which the concentrates are shipped, and concentrates shipped in this manner will drain in such a "traveling filter" to about 25 per cent. or 30 per cent. moisture. In case of a long haul, this is expensive both in freight and leaks. Filters are being used in nearly all of the larger plants. OLIVER and Portland filters turn out a satisfactory product with 10 per cent. to 15 per cent. moisture, and pressure filters like the KELLY while more cumbersome and expensive to operate, are giving products ranging from 6 per cent. to 10 per cent. moisture.

Flotation Practice with Complex Sulphides

Where the flotation concentrates consist of several mixed sulphides which it is advisable to separate they are run over concentrating tables after breaking the froth. This idea is old,

but its application in the United States is relatively new. Mixed concentrates made on Minerals Separation, CALLOW, McQUISTEN and DE BAVAY machines are now being treated in this manner in the United States.

The mention of separation of mixed sulphides in flotation concentrates suggests the work on preferential (selective) flotation. In this field there is much work being done in laboratories, and many seemingly good results are being obtained. However, most work of this kind is being guarded closely. In four separate and distinct places the idea has been adopted of separating galena selectively in the presence of sphalerite by an exact proportioning of a suitable oil, adding only enough to float the galena. This idea is old, but to see it worked out in detail and applied in the works (as it is in three instances) is gratifying.

Most of the preferential methods have consisted in the treatment of ore by some method which modifies one of the flotative minerals and prevents its floating. The HORWOOD process (a slight roast to deaden the surfaces of lead-sulphide particles and prevent their floating, while the zinc sulphide is unaffected) has been tried experimentally in at least five instances, and more or less encouraging results have been obtained. A patent of GREENWAY and LOWRY reveals another proposal of adding chromates to the mill water to act on one sulphide while the other is unaffected and can still be floated. Still other methods of getting preferential flotation have been experimented with— by proper preliminary treatment of the oil, such as emulsifying, fractionally distilling, treatment with proper electrolytes, acids or other chemicals. This work is nearly all experimental-laboratory work.

Retreatment of Tailings

The cleaning of tailings is being accomplished, as a rule, by further addition of oil and retreatment in other flotation cells. The "step" addition of oils is claimed by the Butte metallurgists as a contribution of their own. Almost universally, oleic acid is used in the cleaning treatment of the tails of lead- or zinc-sulphide ores. It seems to be especially adapted to the purpose, though it is hard to get high-grade concentrates by its use.

Incidentally, the effect of adding an excess of any flotation oil seems to be the formation of lower grade concentrates, which are hard to clean. Moreover, the froth is liable to be too tough and permanent to permit of its being easily broken after removal from the machine. Oil or substances immiscible with water and generally understood by that name are not necessary to flotation. Many soluble frothing agents are used that are not "oils" in any sense of the term. As the term "soluble frothing agents" has been mentioned in many of the more recent patents, the term "oil flotation" might be advantageously dropped before it gains too much headway.

Flotation Oils

The subject of oils is a most important one, and more experimental work has been done on this particular phase of the subject than on any other. Attempts to determine which oils may be best suited to the treatment of certain minerals have not resulted in deciding on any particular oil that will always concentrate a certain mineral in all cases. Pine oil is a favorite for floating both lead and zinc sulphides, though the wood creosotes are close competitors. Eucalyptus oil seems in many cases to work better than either of these, but it is too costly.

Petroleum products appear to be sufficiently selective for copper concentration; but in the concentration of lead or zinc sulphides they seem to float too much gangue. Such being the case, it may be said that petroleum oils are not well adapted to flotation work upon lead-zinc ores, as in the treatment of such ores it is necessary to produce concentrates which shall contain not less than 45 per cent. lead or zinc. On the other hand, particularly high-grade concentrates are not necessary in copper work, and a high extraction, with concentrates having a tenor of 10 per cent. to 25 per cent. Cu, is usually obtainable.

Delivered, pine oil costs from 25 cts. to 30 cts. per gallon; creosote 18 cts. to 25 cts.; eucalyptus oil, $1.50 to $2 per gallon. (Roughly, there are 8 lb. of oil in a gallon.) The petroleum products used can be bought for from 5 cts. to 10 cts. per gallon.

Use of Acid in Flotation

In the use of acid in the mill water the practice differs sharply. The addition of acid seems to improve selective action, especially on galena, sphalerite and pyrite, and appears to be effective for the purpose of getting clean concentrates with a minimum of gangue. The removal of oxidized films from sulphide particles is one result. It could doubtless be used in many places where it is not now used. On the other hand, it has been found in certain instances that the presence of an acid was fatal to the process. As a rule sulphuric acid is the cheapest acid available and so is generally the one used. The amount of acid used is somewhat lower than formerly, when from 0.5 per cent. to 1 per cent. H_2SO_4 was used in the mill water. Now the average practice is from 0.2 per cent. to 0.5 per cent.

The presence of any electrolyte seems to have a marked effect on flotation, and a set of experiments on some well-known ore, using distilled water instead of mill water, is therefore of great interest. In fact, the analysis of mill water from some of the mills where different methods are employed for treating ores that seem to be almost identical may reveal some interesting points. In our own laboratory the possibilities of new conditions arising from the use of water from the Great Salt Lake is a question under investigation.

Temperature Increases Selective Action

Whether temperature is an important item or not is also under dispute. On nearly every ore being treated it is possible to get

good work done with unheated mill pulp; but a better grade of concentrates can often be obtained by heating the solution. It makes the oil and water less viscous, so that a given amount of oil will go a little farther. Moreover, less gangue rises through the more fluid water. The consideration of what would happen in the way of flotation of gangue if a mill solution composed of thick molasses were used illuminates this point. Further, the selective action due to the presence of an acid or electrolyte is promoted by a higher temperature. Hence, heating the mill pulp will be of value in those instances where concentrates of high metal tenor are wanted, as when working on lead- and zinc-sulphide ores. The temperature to which the mill water is heated is not over 65°C. (149°F.) in any case, and usually not over 50°C. (112°F.). The cost of heating to these temperatures is from 5 cts. to 10 cts. per ton of dry slimes.

Developments in Mechanical Agitation

The tendency in all mechanical-agitation methods of flotation (as distinguished from pneumatic methods) seems to be toward the most careful and rigid practice possible. A study is being made of the exact proportioning of compartments, of the beating blades or paddles on the impellers, and of the spitzkasten or settling boxes. For example, inclined blades seem to wear better than vertical ones.

The addition of froth rakes or hoes has also been made to nearly all such machines so as to remove the froth as fast as it is formed rather than to let it accumulate until it overflows by gravity. The removal of the froth in this manner avoids the breaking of bubbles and thus prevents the mineral getting back into the pulp and being lost. It also increases the capacity of the machine and permits the use of only enough oil to give a froth that breaks easily and carries little gangue.

Individual drive of each impeller from a small special motor has been adopted in one design, rather than the use of a line shaft with either belt or gear drive of each impeller. This drive doubtless costs much more for installation, but gives flexibility of control of each individual cell. Other mechanical means of mixing are being tried, such as the centrifugal pump which was used in Australia some time ago. This arrangement seems to give a low extraction and high-grade concentrates, a result capable of explanation on the assumption that the flotation conditions obtained are rather poor and that hence only the purest mineral floats, while middlings are unaffected. Such a practice makes cleaning of the tails by further treatment necessary. Having adjustable openings between beating compartments and spitzkasten seems to be nearly universal practice, though in a few of the mills visited the openings are hardly ever manipulated.

A preliminary mixing of the oil with the pulp is suggested as an interesting possibility as a result of some experiments conducted by three large companies, in which the addition of the oil was made before the material treated was passed through a

tube mill. The mixing conditions were ideal and the tube-mill discharge could be run directly into a spitzkasten for separation of froth, or into pneumatic-flotation cells. This idea will doubtless be followed further.

Variation in Pneumatic-flotation Cells

Contrary to the tendency in mechanical-agitation schemes, the pneumatic-flotation machinery is being modified, apparently, toward the greatest freedom of design possible. As an instance, the CALLOW cell is designed with a slanting bottom to facilitate discharge of tailings. Some mill men find flat bottoms to work just as well. In fact, every possible modification of a bottom seems to be at work. Single and quadruple thicknesses of canvas are used. The canvas may be clamped and bolted between two strong grids of perforated sheet steel or it may be supported against some wire cloth and tacked on. It may likewise not be supported in any manner, but simply stretched tight and held by a piece of rope driven in a groove which extends around the inside of the bottom of the machine. The last-cited method seems to be about as successful as any for changing bottoms when the canvas becomes worn out.

Before treatment in the pneumatic-flotation cell the pulp is commonly mixed with the oil in a Pachuca mixing tank. In several instances a number of these Pachucas are placed in series and a good grade of froth is drawn direct from the tops of them. It is quite likely that radical changes in design will result from this experimental work. Both wooden and metal constructions are used, the metal cells costing nearly twice as much as the wooden ones.

Electrical Flotation

Among the new proposals appearing during the last year was the FIELDS electric-flotation process. In this process it is proposed to accomplish flotation by means of hydrogen bubbles developed by electrolysis of the solution mixed with the pulp. FIELDS also proposes to use air lifts to keep the pulp in suspension. It is claimed that no oil is necessary, but that it helps. The special application of this process is stated to be on partly oxidized copper ores, where the copper sulphides can be floated, and by use of a solution of a sulphate or a chloride the oxidized copper will go in solution at the anode and a rough copper cathode will finally result. Promising results have been obtained, but at an expenditure of power of about 10 times that anticipated. Whether or not this process can be made commercially feasible is a matter of considerable interest.

Flotation of Oxidized and Other Minerals

In the flotation of oxidized and other minerals much quiet work is being done. The most promising method proposed is that of "sulphidizing" oxidized minerals of copper and of lead by treatment with the proper soluble sulphide and then floating the artificial sulphides formed. This idea has been tried

principally on copper ores with fair results. Treatment with hydrogen-sulphide gas, either of dry ore or suspended pulp, works well, or the sulphidizing may go on during flotation by use of ground matte and acid to react on each other and form H_2S; or solutions of hydrogen sulphide, alkaline sulphides, alkaline-earth sulphides and other compounds can be used with more or less success. The concentrates formed are never of high grade, as a great deal of gangue is carried up, especially iron. Similar work is being done in our laboratory on low-grade oxidized ores of lead, but a concentrate with only 20 per cent. of lead is a different thing from a 20 per cent. copper concentrate. The present outlook seems to be that the process will apply only to oxidized copper ores. Oxidized zinc ores seem to be unaffected by the process.

SECTION VII

CYANIDATION

Flow of Sand and Water through Spigots[1]

RELATION OF COMPOSITION TO VISCOSITY OF MIXTURES OF SAND AND WATER

Kilograms sand and water	Kilograms sand	Kilograms and liters water	Liters sand	Liters sand and water	Per cent. sand by volume	Per cent. sand by weight	Viscosity of mixture
9.20	0.00	9.20	0.000	9.20	0.00	0.00	1.00
9.30	0.45	8.85	0.165	9.02	1.83	4.84	1.02
9.35	1.10	8.25	0.405	8.66	4.68	11.8	1.06
9.35	1.40	7.95	0.515	8.47	6.08	15.0	1.09
9.40	1.90	7.50	0.699	8.20	8.53	20.2	1.12
9.40	1.95	7.45	0.717	8.17	8.78	20.8	1.13
9.55	2.20	7.35	0.809	8.16	9.92	22.0	1.13
9.20	2.25	6.95	0.827	7.78	10.6	24.4	1.18
9.05	2.50	6.55	0.920	7.47	12.3	27.6	1.23

A concrete example, illustrating the use of the data given above, may prove of interest. It is desired to discharge from the pocket of a classifier 40 tons of sand per 24 hours together with water in the ratio of 1 part of sand to 3 parts of water by weight. The head of water above the spigot is 3 ft. The form of the spigot is that of a short tube with a conical mouth on the influx end. The mean specific gravity of the sand is 2.81. What must be the diameter of the spigot opening? For the sake of convenience, metric units are used in making the calculation. The area of the spigot opening may be obtained from the formula:

$$a = \frac{fq}{c\sqrt{2gh}}$$

Taking up the terms on the right hand of the equation in order, f the viscosity, may be estimated as follows: The weight ratio of water to sand in the mixture to be discharged is 3 to 1. Considering 100 grams of the mixture, the weight of water is 75 grams; its volume is 75 cc. The volume of the sand is 25 grams $\div$ 2.81 (the density of the sand) = 8.9 cc. The total volume of 100 grams of the mixture is $75 + 8.9 = 83.9$ cc. Hence the percentage of sand by volume in the mixture is $8.9 \div 83.9 = 10.6$. From the lower curve of Fig. 1, the viscosity of a mixture containing 10.6 per cent. of sand by volume is 1.17. Therefore, $f = 1.17$. The quantity of sand discharged per 24 hours is 40

[1] RICHARDS and DUDLEY, *Trans. A. I. M. E.*, January, 1915.

tons. One ton per 24 hours is 0.631 kg. per minute. Forty tons per 24 hours is 40 × 0.631 = 25.2 kg. per minute. The volume of sand per minute is 25.2 ÷ 2.81 (the density) = 8.98 liters. The quantity of water per minute is three times that of the sand, 25.2 × 3 = 75.6 kg. = 75.6 liters. The total volume of sand and water per minute is 8.98 (sand) + 76.5 (water) = 85.5 ÷ 60 = 1.43 liters = 1430 cc.

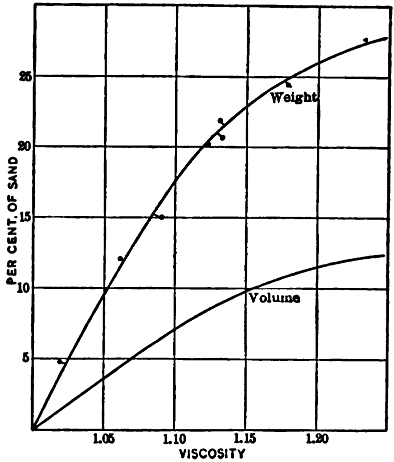


FIG. 1.—Graphic representation of results shown in table on p. 403.

Since the spigot is to consist of a short tube with a conical mouth on the influx end, the coefficient of discharge, c, may be assumed as 0.88. Substituting these values in the above equation gives for the area of the spigot opening:

$$a = \frac{1.17 \times 1430}{0.88\sqrt{2 \times 980 \times 914}} = 1.42 \text{ sq. cm.}$$

The diameter may be obtained from the relation:

$$d = 2\sqrt{\frac{a}{n}} \quad d = 1.35 \text{ cm.} = 0.53 \text{ in.}$$

Pulp Constants

In an article by G. H. CLEVENGER, H. W. YOUNG and T. N. TURNER (*Eng. and Min. Journ.*, Dec. 19, 1914) it was shown that the ordinary calculations for contents of tanks, weights of tailings, etc., based on the assumption that the specific gravity of the solution was 1, were incorrect by large amounts. CLEVENGER worked out a set of complete tables covering these constants, of which only the basic formulas are here given.

Let a = Specific gravity of wet pulp.
S = Specific gravity of dry slime.

V = Total volume of wet pulp.
m = Total weight of dry slime in wet pulp.
c = Volume of solution in wet pulp.
d = Specific gravity of solution.
P = Percentage of dry slime in wet pulp.

$$a = \frac{m + cd}{V} \qquad S = \frac{m}{(V - c)}$$

Solving for c, equating values, simplifying and solving for m:

$$m = \frac{SV(a - d)}{(S - d)}$$

P is obtained by multiplying the above value of m by 100 and dividing by weight of the wet pulp, Va:

$$P = \frac{100S(a - d)}{a(S - d)}$$

The error introduced by assuming $d = 1$ is not a negligible one.

SPECIFIC GRAVITY OF WORKING CYANIDE SOLUTIONS

Solution	Specific gravity	
Fresh solution	....	1.00170
Butters plant, Virginia City, Nev.	Heads	1.00281
Butters plant, Virginia City, Nev.	Tails	1.00279
Belmont plant, Tonopah, Nev.	Heads	1.00881
Belmont plant, Tonopah, Nev.	Tails	1.00873
Montana-Tonopah, Tonopah, Nev.	Heads	1.00314
Empire, Grass Valley, Calif.	Heads	1.00142
Portland, Colorado Springs, Colo.	Heads	1.01000
South Africa, average	....	1.00210
Pittsburgh-Silver Peak, Blair, Nev.	Heads	1.00309

SLIME COAGULANTS[1]

Substances	Quantities required by weight, to produce equal effects
Aluminum sulphate	100
Alum (potash)	143
Ferric sulphate	223
Alum (ammonium)	252
Alum (ammonium-chromium)	295
Lime	654
Magnesia	748
Alum (potassium-chromium)	958
Calcium chloride	1,095
Calcium carbonate	1,215
Calcium sulphate	2,870
Magnesium sulphate	3,460
Sodium chloride	45,900
Sodium sulphate	61,700

[1] MEGRAW, "Practical Data for the Cyanide Plant," adapted from JULIAN and SMART.

Number of Cubic Feet for each Foot of Depth of Cylindrical Tanks[1]

Diam., inches	Diameter, feet										
	10	11	12	13	14	15	16	17	18	19	20
0	78.54	95.03	113.1	132.7	153.9	176.7	201.1	227.0	254.5	283.5	314.2
½	79.19	95.75	113.9	133.5	154.8	177.7	202.1	228.1	255.6	284.7	315.5
1	79.85	96.48	114.7	134.4	155.8	178.7	203.2	229.2	256.8	286.0	316.8
1½	80.51	97.20	115.5	135.3	156.7	179.7	204.2	230.3	258.0	287.2	318.1
2	81.18	97.93	116.3	136.2	157.6	180.7	205.3	231.5	259.2	288.5	319.4
2½	81.85	98.66	117.1	137.0	158.5	181.7	206.3	232.6	260.4	289.7	320.7
3	82.52	99.40	117.9	137.9	159.5	182.7	207.4	233.7	261.6	291.0	322.1
3½	83.19	100.1	118.7	138.7	160.4	183.7	208.4	234.8	262.8	292.3	323.4
4	83.86	100.9	119.5	139.6	161.4	184.7	209.5	236.0	264.0	293.6	324.7
4½	84.54	101.6	120.3	140.5	162.3	185.7	210.6	237.1	265.2	294.8	326.0
5	85.22	102.4	121.1	141.4	163.2	186.7	211.7	238.2	266.4	296.1	327.4
5½	85.90	103.1	121.9	142.2	164.1	187.7	212.7	239.3	267.6	297.3	328.7
6	86.59	103.9	122.7	143.1	165.1	188.7	213.8	240.5	268.8	298.6	330.1
6½	87.28	104.6	123.5	144.0	166.0	189.7	214.9	241.6	270.0	299.9	331.4
7	87.97	105.4	124.4	144.9	167.0	190.7	216.0	242.8	271.2	301.2	332.8
7½	88.66	106.1	125.2	145.8	167.9	191.7	217.1	243.9	272.4	302.5	334.1
8	89.36	106.9	126.0	146.7	168.9	192.8	218.2	245.1	273.7	303.8	335.5
8½	90.06	107.6	126.8	147.6	169.9	193.8	219.3	246.2	274.9	305.1	336.8
9	90.76	108.4	127.7	148.5	170.9	194.8	220.4	247.4	276.1	306.4	338.2
9½	91.47	109.2	128.5	149.4	171.8	195.8	221.5	248.6	277.3	307.6	339.5
10	92.18	110.0	129.4	150.3	172.8	196.9	222.6	249.8	278.6	308.9	340.9
10½	92.89	110.7	130.2	151.2	173.8	197.9	223.7	250.9	279.8	310.2	342.2
11	93.60	111.5	131.0	152.1	174.8	199.0	224.8	252.1	281.0	311.5	343.6
11½	94.31	112.3	131.8	153.0	175.7	200.0	225.9	253.3	282.2	312.8	345.0

Number of Cubic Feet for each Foot of Depth of Cylindrical Tanks.[1] *Continued*

Diam., inches	Diameter, feet										
	21	22	23	24	25	26	27	28	29	30	31
0	346.4	380.1	415.5	452.4	490.9	530.9	572.6	615.8	660.5	706.9	754.8
½	347.7	381.5	417.0	453.9	492.5	532.6	574.3	617.6	662.4	708.8	756.8
1	349.1	383.0	418.5	455.5	494.2	534.3	576.1	619.4	664.3	710.8	758.8
1½	350.5	384.4	420.0	457.1	495.8	536.0	577.8	621.2	666.2	712.7	760.8
2	351.9	385.9	421.5	458.7	497.4	537.8	579.6	623.1	668.1	714.7	762.9
2½	353.3	387.3	423.0	460.3	499.0	539.5	581.4	624.9	670.0	716.7	764.9
3	354.7	388.8	424.6	461.9	500.7	541.2	583.2	626.8	672.0	718.7	767.0
3½	356.0	390.2	426.1	463.4	502.4	542.9	585.0	628.6	673.9	720.7	769.0
4	357.4	391.7	427.6	465.0	504.1	544.6	586.8	630.5	675.8	722.7	771.1
4½	358.8	393.2	429.1	466.6	505.7	546.3	588.6	632.3	677.7	724.6	773.1
5	360.2	394.7	430.7	468.2	507.4	548.1	590.4	634.2	679.6	726.6	775.2
5½	361.6	396.1	432.2	469.8	509.0	549.8	592.2	636.0	681.5	728.6	777.2
6	363.1	397.6	433.7	471.4	510.7	551.5	594.0	637.9	683.5	730.6	779.3
6½	364.5	399.1	435.2	473.0	512.3	553.2	595.8	639.8	685.4	732.6	781.3
7	365.9	400.6	436.8	474.6	514.0	555.0	597.6	641.7	687.4	734.6	783.4
7½	367.3	402.0	438.3	476.2	515.7	556.7	599.4	643.5	689.3	736.6	785.5
8	368.7	403.5	439.9	477.9	517.4	558.5	601.2	645.4	691.2	738.6	787.6
8½	370.1	405.0	441.4	479.5	519.1	560.2	603.0	647.3	693.1	740.6	789.6
9	371.5	406.5	443.0	481.1	520.8	562.0	604.8	649.2	695.1	742.0	791.7
9½	372.9	408.0	444.5	482.7	522.4	563.7	606.6	651.0	697.0	744.6	793.8
10	374.4	409.5	446.1	484.4	524.1	565.6	608.4	652.9	699.0	746.7	795.9
10½	375.8	411.0	447.7	486.0	525.8	567.2	610.2	654.8	700.9	748.7	798.0
11	377.3	412.5	449.3	487.6	527.5	569.0	612.1	656.7	702.9	750.7	800.1
11½	378.7	414.0	450.8	489.2	529.2	570.8	613.9	658.6	704.9	752.7	802.1

NUMBER OF CUBIC FEET FOR EACH FOOT OF DEPTH OF CYLINDRICAL TANKS.[1] *Continued*

Diameter, inches	Diameter, feet										
	32	33	34	35	36	37	38	39	40	41	2
0	804.2	855.3	907.9	962.1	1018	1075	1134	1195	1257	1320	1385
½	806.3	857.4	910.1	964.4	1020	1077	1136	1197	1259	1323	1388
1	808.4	859.6	912.4	966.7	1023	1080	1139	1200	1262	1326	1391
1½	810.5	861.8	914.6	969.0	1025	1082	1141	1202	1264	1328	1393
2	812.6	864.0	916.8	971.3	1027	1085	1144	1205	1267	1331	1396
2½	814.7	866.1	919.0	973.6	1029	1087	1146	1207	1269	1333	1399
3	816.9	868.3	921.3	975.9	1032	1090	1149	1210	1272	1336	1402
3½	819.0	870.5	923.5	978.2	1034	1092	1151	1212	1275	1339	1405
4	821.1	872.7	925.8	980.5	1037	1095	1154	1215	1278	1342	1408
4½	823.2	874.8	928.0	982.8	1039	1097	1156	1217	1280	1344	1410
5	825.3	877.0	930.3	985.2	1042	1100	1159	1220	1283	1347	1413
5½	827.4	879.2	932.5	987.5	1044	1102	1161	1222	1285	1350	1416
6	829.6	881.4	934.8	989.8	1046	1104	1164	1225	1288	1353	1419
6½	831.7	883.6	937.0	992.1	1048	1106	1166	1228	1291	1355	1421
7	833.8	885.8	939.3	994.5	1051	1109	1169	1231	1294	1358	1424
7½	835.9	888.0	941.6	996.8	1053	1111	1171	1233	1296	1361	1427
8	838.1	890.2	943.9	999.1	1056	1114	1174	1236	1299	1364	1430
8½	840.2	892.4	946.1	1001	1058	1116	1176	1238	1301	1366	1432
9	842.4	894.6	948.4	1004	1061	1119	1179	1241	1304	1369	1435
9½	844.5	896.8	950.1	1006	1063	1121	1181	1243	1307	1371	1438
10	846.7	899.0	953.0	1008	1066	1124	1184	1246	1310	1374	1441
10½	848.8	901.2	955.2	1010	1068	1126	1186	1248	1312	1377	1444
11	851.0	903.5	957.5	1013	1070	1129	1189	1251	1315	1380	1447
11½	853.1	905.7	959.8	1015	1072	1131	1192	1254	1317	1382	1450

NUMBER OF CUBIC FEET FOR EACH FOOT OF DEPTH OF CYLINDRICAL TANKS.[1] *Continued*

Diameter, inches	Diameter, feet											
	43	44	45	46	47	48	49	50	51	52	53	54
0	1452	1521	1590	1662	1735	1810	1886	1963	2043	2124	2206	2290
½	1455	1523	1593	1665	1738	1813	1889	1966	2046	2127	2209	2293
1	1458	1526	1596	1668	1741	1816	1892	1970	2050	2131	2213	2297
1½	1460	1529	1599	1671	1744	1819	1895	1973	2053	2134	2216	2300
2	1463	1532	1602	1674	1747	1822	1899	1977	2056	2137	2220	2304
2½	1466	1535	1605	1677	1750	1825	1902	1980	2059	2140	2223	2307
3	1469	1538	1608	1680	1753	1828	1905	1983	2063	2144	2227	2311
3½	1472	1541	1611	1683	1756	1831	1908	1986	2066	2147	2230	2315
4	1475	1544	1614	1686	1760	1835	1911	1990	2070	2151	2234	2319
4½	1477	1546	1617	1689	1763	1838	1914	1993	2073	2154	2237	2322
5	1480	1549	1620	1692	1766	1841	1918	1996	2076	2158	2241	2326
5½	1483	1552	1623	1695	1769	1844	1921	1999	2079	2161	2244	2329
6	1486	1555	1626	1698	1772	1847	1924	2003	2083	2165	2248	2333
6½	1489	1558	1629	1701	1775	1850	1927	2006	2086	2168	2251	2336
7	1492	1561	1632	1704	1778	1854	1931	2010	2090	2172	2255	2340
7½	1495	1564	1635	1707	1781	1857	1934	2013	2093	2175	2258	2343
8	1498	1567	1638	1710	1785	1860	1937	2016	2097	2179	2262	2347
8½	1500	1570	1641	1713	1788	1863	1940	2019	2100	2182	2265	2351
9	1503	1573	1644	1717	1791	1867	1944	2023	2103	2185	2269	2354
9½	1506	1576	1647	1720	1794	1870	1947	2026	2106	2188	2273	2357
10	1509	1579	1650	1723	1797	1873	1950	2029	2110	2192	2276	2361
10½	1512	1582	1653	1726	1800	1876	1953	2032	2113	2195	2279	2365
11	1515	1585	1656	1729	1803	1879	1957	2036	2117	2199	2283	2369
11½	1518	1587	1659	1732	1806	1882	1960	2039	2120	2202	2286	2372

Number of Cubic Feet for each Foot of Depth of Cylindrical Tanks.[1] *Continued*

Diameter, inches	Diameter, feet										
	55	56	57	58	59	60	61	62	63	64	65
0	2376	2463	2552	2642	2734	2827	2922	3019	3117	3217	3318
½	2379	2466	2555	2646	2738	2831	2926	3023	3121	3221	3322
1	2383	2470	2559	2650	2742	2835	2930	3027	3125	3225	3327
1½	2386	2474	2563	2653	2745	2839	2934	3031	3129	3229	3331
2	2390	2478	2567	2657	2749	2843	2938	3035	3134	3234	3335
2½	2393	2481	2570	2661	2753	2847	2942	3039	3138	3238	3339
3	2397	2485	2574	2665	2757	2851	2946	3043	3142	3242	3344
3½	2401	2488	2578	2669	2761	2855	2950	3047	3146	3246	3348
4	2405	2492	2582	2673	2765	2859	2954	3052	3150	3251	3352
4½	2408	2496	2585	2676	2769	2863	2958	3056	3154	3255	3356
5	2412	2500	2589	2680	2773	2867	2963	3060	3159	3259	3361
5½	2415	2503	2593	2684	2777	2871	2967	3064	3163	3263	3365
6	2419	2507	2597	2688	2781	2875	2971	3068	3167	3267	3370
6½	2422	2511	2600	2691	2784	2879	2975	3072	3171	3271	3374
7	2426	2515	2604	2695	2788	2883	2979	3076	3175	3276	3378
7½	2430	2518	2608	2699	2792	2887	2983	3080	3179	3280	3382
8	2434	2522	2612	2703	2796	2891	2987	3084	3184	3284	3387
8½	2437	2525	2615	2707	2800	2895	2991	3088	3188	3288	3391
9	2441	2529	2619	2711	2804	2899	2995	3093	3192	3293	3395
9½	2444	2533	2623	2715	2808	2903	2999	3097	3196	3297	3399
10	2448	2537	2627	2719	2812	2907	3003	3101	3200	3301	3404
10½	2452	2540	2630	2722	2816	2910	3007	3105	3204	3305	3408
11	2456	2544	2634	2726	2820	2914	3011	3109	3209	3310	3413
11½	2459	2548	2638	2730	2823	2918	3015	3113	3213	3314	3417

Number of Cubic Feet for each Foot of Depth of Cylindrical Tanks.[1] *Continued*

Diameter, inches	Diameter, feet										
	66	67	68	69	70	71	72	73	74	75	76
0	3421	3526	3632	3739	3848	3959	4072	4185	4301	4418	4536
½	3425	3530	3636	3743	3853	3963	4076	4190	4306	4423	4541
1	3430	3534	3641	3748	3858	3968	4081	4195	4311	4428	4546
1½	3434	3538	3645	3752	3862	3973	4085	4200	4315	4433	4551
2	3438	3543	3650	3757	3867	3978	4090	4205	4320	4438	4556
2½	3442	3547	3654	3761	3871	3982	4095	4209	4325	4442	4561
3	3447	3552	3658	3766	3876	3987	4100	4214	4330	4447	4566
3½	3451	3556	3662	3770	3880	3991	4104	4219	4335	4452	4571
4	3456	3561	3667	3775	3885	3996	4109	4224	4340	4457	4576
4½	3460	3565	3671	3780	3889	4001	4114	4228	4344	4462	4581
5	3465	3570	3676	3785	3894	4006	4119	4233	4349	4467	4586
5½	3469	3574	3680	3789	3899	4010	4123	4238	4354	4472	4591
6	3473	3578	3685	3794	3904	4015	4128	4243	4359	4477	4596
6½	3477	3582	3689	3798	3908	4020	4133	4248	4364	4482	4601
7	3482	3587	3694	3803	3913	4025	4138	4253	4369	4487	4606
7½	3486	3591	3698	3807	3917	4029	4142	4257	4374	4492	4611
8	3491	3596	3703	3812	3922	4034	4147	4262	4379	4497	4616
8½	3495	3600	3707	3816	3926	4038	4152	4267	4383	4502	4621
9	3499	3605	3712	3821	3931	4043	4157	4272	4388	4507	4626
9½	3503	3609	3716	3825	3936	4048	4161	4276	4393	4512	4631
10	3508	3614	3721	3830	3941	4053	4166	4281	4398	4517	4636
10½	3512	3618	3725	3834	3945	4057	4171	4286	4403	4522	4641
11	3517	3623	3730	3839	3950	4062	4176	4291	4408	4527	4647
11½	3521	3627	3734	3843	3954	4067	4180	4296	4413	4531	4652

NUMBER OF CUBIC FEET FOR EACH FOOT OF DEPTH OF CYLINDRICAL TANKS.[1] *Continued*

Diameter, inches	Diameter, feet										
	77	78	79	80	81	82	83	84	85	86	87
0	4657	4778	4902	5027	5153	5281	5411	5542	5675	5809	5945
½	4662	4783	4907	5032	5158	5286	5416	5547	5680	5814	5950
1	4667	4789	4912	5037	5164	5292	5421	5553	5686	5820	5956
1½	4672	4794	4917	5042	5169	5297	5426	5558	5691	5825	5961
2	4677	4799	4922	5048	5174	5303	5432	5564	5697	5831	5967
2½	4682	4804	4927	5053	5179	5308	5437	5569	5702	5837	5973
3	4687	4809	4933	5058	5185	5313	5443	5575	5708	5843	5979
3½	4692	4814	4938	5063	5190	5318	5448	5580	5713	5848	4984
4	4697	4819	4943	5069	5195	5324	5454	5586	5719	5854	5990
4½	4702	4824	4948	5074	5200	5329	5459	5591	5724	5859	5996
5	4707	4830	4954	5079	5206	5335	5465	5597	5730	5865	6002
5½	4712	4835	4959	5084	5211	5340	5470	5602	5735	5871	6007
6	4717	4840	4964	9509	5217	5346	5476	5608	5741	5877	6013
6½	4722	4845	4969	5095	5222	5351	5481	5613	5747	5882	6019
7	4727	4850	4974	5100	5227	5356	5487	5619	5753	5888	6025
7½	4732	4855	4979	5105	5232	5361	5492	5624	5758	5893	6030
8	4738	4860	4985	5111	5238	5367	5498	5630	5764	5899	6036
8½	4743	4865	4990	5116	5243	5372	5503	5635	5769	5905	6042
9	4748	4871	4995	5121	5249	5378	5509	5641	5775	5911	6048
9½	4753	4876	5000	5126	5254	5383	5514	5646	5780	5916	6053
10	4758	4881	5006	5132	5260	5389	5520	5652	5786	5922	6059
10½	4763	4886	5011	5137	5265	5394	5525	5657	5792	5927	6065
11	4768	4891	5016	5142	5270	5400	5531	5663	5798	5933	6071
11½	4773	4896	5021	5147	5275	5405	5536	5669	5803	5939	6076

NUMBER OF CUBIC FEET FOR EACH FOOT OF DEPTH OF CYLINDRICAL TANKS.[1] *Continued*

Diameter, inches	Diameter, feet											
	88	89	90	91	92	93	94	95	96	97	98	99
0	6082	6221	6362	6504	6648	6793	6940	7088	7238	7390	7543	7698
½	6088	6227	6368	6510	6654	6799	6946	7094	7244	7396	7549	7704
1	6094	6233	6374	6516	6660	6805	6952	7101	7251	7403	7556	7711
1½	6099	6238	6379	6522	6666	6811	6958	7107	7257	7409	7562	7717
2	6105	6244	6385	6528	6672	6817	6864	7113	7263	7415	7569	7724
2½	6111	6250	6391	6534	6678	6823	6970	7119	7269	7421	7575	7730
3	6117	6256	6397	6540	6684	6829	6977	7126	7276	7428	7581	7737
3½	6122	6262	6403	6546	6690	6835	6983	7132	7282	7434	7587	7743
4	6128	6268	6409	6552	6696	6842	6989	7138	7289	7441	7594	7750
4½	6134	6274	6415	6558	6702	6848	6995	7144	7295	7447	7600	7756
5	6140	6280	6421	6564	6708	6854	7001	7151	7301	7453	7607	7763
5½	6145	6285	6427	6570	6714	6860	7007	7157	7307	7459	7613	7769
6	6151	6291	6433	6576	6720	6866	7014	7163	7314	7466	7620	7776
6½	6157	6297	6438	6582	6726	6872	7020	7169	7320	7472	7626	7782
7	6163	6303	6444	6588	6732	6878	7026	7176	7326	7479	7633	7789
7½	6169	6309	6450	6594	6738	6884	7032	7182	7332	7485	7639	7795
8	6175	6315	6456	6600	6744	6891	7039	7188	7339	7492	7646	7802
8½	6180	8320	6462	6606	6750	6897	7045	7194	7345	7498	7652	7808
9	6186	6326	6468	6612	6756	6903	7051	7201	7352	7505	7659	7815
9½	6192	6332	6474	6618	6762	6909	7057	7207	7358	7511	7665	7821
10	6198	6338	6480	6624	6769	6915	7063	7213	7364	7517	7672	7828
10½	6203	6344	6486	6630	6775	6921	7069	7219	7370	7523	7678	7834
11	6209	6350	6492	6636	6781	6927	7076	7226	7377	7530	7685	7841
11½	6215	6356	6498	6642	6787	6933	7082	7232	7383	7536	7691	7847
												7854

[1] G. H. CLEVENGER, *et al.*, "Pulp Constants," *Eng. and Min. Jour.*, Dec.), 1914.

Operating Data on Dorr Thickeners[1]

Mill	Sq. ft. settling area per ton of solids thickened per 24 hr.	Sq. ft. settling area per gallon overflowed per minute	Remarks
San Rafael, Mexico	4.5	....	Tube-mill product, 75 per −200 mesh, discharge per cent. solids.
Liberty Bell, Colorado.	15.0	12.6	Tube-mill product, much argillaceous slime. Discl 33 per cent. solids: +10 per cent.; +200, 13 per c −200, 70 per cent. Feed Solution fed at capacity; s not. Large area per g overflowed per minute di density of underflow nature of the slime.
Mogul, South Dakota.	3.92	....	Tube-mill product, ore silic +60, 0.6 per cent.; + 7.8 per cent.; +200, 26 cent.; −200, 65.6 per Discharge 56 to 59 per cent ids. Continuous decanta
Batopilas, Mexico.	0.6 to 0.9	....	40-mesh product; 90 per passing 100 mesh.
Zambona, Mexico.	3.1	....	Tube-mill product. Discl 40 per cent. solids.
Dominion, Ontario	5.4	....	Tube-mill product, 88 per −200 mesh, ore diabase. charge 40 per cent. so Feed 6:1.
Porcupine-Crown, Ontario.	4.25	....	Tube-mill product, 75 per −200 mesh. Discharge 6 cent. solids. Quartz ore. tinuous decantation. 5.1 sq. ft. settling area pe settles to 71 to 73 per solids.
El Palmarito, Mexico.	4.5	....	Tube-mill product: pure q zite, 97 per cent. −200 n Feed 7:1. Discharge 65 per cent. solids. Contin decantation.
Amparo, Jalisco, Mex.	4.9	1.4	Tube-mill product, silic 93.5 per cent. −200 n Feed 24.5:1. Discharge per cent. solids; used to vanners.
Veta, Colorado, Parral, Mex.	5.0	3⅓[a]	Tube-mill product, rather a laceous: 71 per cent. - mesh. Feed 11:1. Discl 33 per cent. solids for agit Have settled to 65 per solids.
Smuggler-Union, Telluride, Colo.	....	....	Very clayey slime with cl fied sand. Screen test: 1.48 per cent.; +60, 7.27 cent.

[1] *Metallurgical and Chemical Engineering*, February, 1915.
a. Not up to capacity of overflow.

OPERATING DATA ON DORR THICKENERS. *Continued*

Mill	Sq. ft. settling area per ton of solids thickened per 24 hr.	Sq. ft. settling area per gallon overflowed per minute	Remarks
Smuggler-Union, Telluride, Colo.	....	....	+100, 14.81 per cent.; +200, 11.63 per cent.; −200, 65.81 per cent.
	30.0	26.0	Settling from cold water, slightly alkaline. Feed 8:1. Discharge 50 per cent. solids, 1.429 sp. gr.
	10.0	....	Settling from cyanide solution. Feed, 2.5:1. Discharge 40 per cent. solids, 1.316 sp. gr.
A large copper company, Arizona.	11.6	8.11	Considerable argillaceous slime. Feed 10.4 per cent. solids. Discharge 25.3 per cent. solids.
Pennsylvania Steel, Lebanon, Pa.	14.2	2.48	Thickening ahead of vanner concentration. Feed 2.8 per cent. solids. Discharge 10.6 per cent. solids. Overflow 0.4 per cent. solids, extremely fine, which does not interfere with using water again.
Nevada Consolidated, Ely, Nev.	....	1.25	"Each 17-ft. thickener supplies wash water for 20 Wilfley tables and occasionally for wash on vanners. One thickener has a greater capacity than twelve 8-ft. cones." Area of 17-ft. tank is 226 sq. ft.; of the twelve 8-ft. cones, 525 sq. ft.
Broken Hill, Proprietory, Australia.	....	1.80	Dewatering slime from lead-zinc concentration mill. Feed 100:1. Discharge 55 per cent. solids.
Anaconda Copper, Mont.	....	5.95	Dewatering slime from concentrator. Forty 4-deck thickeners, each 28 ft. in diameter by 3 ft. 3 in. deep, handle about 26,000,000 gal. of pulp per day which contains approximately 2 per cent. solids. A clear overflow obtained, the underflow containing about 15 per cent. solids, which is fed to buddles.

The data given here show that when pulp is carried in cyanide solution a provision of 5 to 6 sq. ft. per ton for a siliceous tube mill product is ample and from 7 to 15 sq. ft. for a clayey material or classified slime product. When very dilute products are handled the area required is determined usually by the gallons per minute to be overflowed.

Power Details for Pachuca Tanks[1]

Tank, diam. × ht., feet	Ore	Charge tons	Free air, cu. ft.	Pressure, lb. per sq. in.	Horse-power	Pulp
7.5×37	Slime.........	15	5	22	0.5	Thin.
7.5×37	Concentrate...	40	17	26	2.0	Thin.
10×40	Slime.........	35	9	22	0.75	Thin.
13×55	Slime.........	110	16	33	1.75	Thin.
10×40	Fine sand.....	50	25	22	2.[illegible]5	Thin.
7.5×37	Battery pulp..	......	14	22	1.4	Thickened.
10×40	Battery pulp..	......	22	23	2.3	Thickened.
13×55	Battery pulp..	......	38	35	4.0	Thickened.

This estimation of horsepower required conforms to the popular ideas on that point. On the basis of some careful tests. which have been made, however, it is probable that actual power consumption is considerably higher.

Principles of Cyanidation

The cyanide process is based upon the solubility of gold and silver, and of some of the compounds of both metals, in an alkaline cyanide. The chemical theory is expressed in Elsner's equation, which was first brought forward by him to show the action of oxygen in the dissolution of precious metals. It is as follows:

$$2Au + 4KCN + O + H_2O = 2KAu(CN)_2 + 2KOH.$$

The usual cyanide salt was formerly potassium cyanide, but for reasons of economy, the sodium salt is principally used at the present time. The commercial product contains about 125 to 128 per cent. of the required compound in terms of KCN.

The essential difference between gold and silver cyanidation is that the gold is almost universally present as a free metal, and the cyanide dissolves the gold only. On the contrary, silver is seldom present in the free state, and usually occurs as a sulphide, chloride, or bromide. The sulphide is the most rebellious of all the compounds, except those which contain highly complex mixtures of antimony, arsenic, cobalt and nickel, but all of these can be treated. Silver sulphide often goes into solution as a sulphide, and it requires some manipulation to separate the silver as a metal.

The consumption of cyanide varies from as low as 0.1 lb. per ton of ore treated, in the case of fine free gold disseminated in pure quartz with no cyanicide, to as much as 5 or 6 lb. per ton in the case of semi-rebellious silver ores. Of course the limit of cyanide consumption depends entirely upon the richness of the ore to be treated. A rich ore will stand a higher consumption than a poor ore. Under ordinary commercial conditions, however, about 5 or 6 lb. per ton would be the limit on ore no matter how high its grade, since the consumption of much more cyanide than this would throw the cost up into competition with the smelting processes, under which circumstances smelting would be preferable to cyanide treatment.

[1] *Eng. and Min. Journ.*, Vol. LXXXVI, 1908, p. 901.

SECTION VIII

FUELS AND REFRACTORIES

CALORIFIC AND EVAPORATIVE VALUES OF VARIOUS LIQUID FUELS[1]

	Sp. gr.	Flash point, °F.	Calorific value by bomb calories	Actual evaporation from and at 212°F.
American residuum	0.886	350	10,904	15.0
Russian Astatki	0.956	308	10,800	14.8
Texas	0.945	244	10,700	14.79
Burma	0.920	230	10,480	14.5
Borneo	0.936	285	10,461	14.0
Mexican crude	0.950	290	10,500	14.90
Oklahoma	0.863	....	10,800	....
Roumanian residue	0.946	....	10,500	....
Trinidad crude	0.945	....	10,200	....
California	0.962	....	10,400	....
Shale oil	0.875	288	10,120	13.8
Blast furnace oil	0.979	206	8,933	12.0
Heavy tar oil	1.084	218	8,916	12.0
Gasoline	0.7100	....	11,733	....
Ohio crude	0.8048	....	11,149	....

[1] Specially compiled for "The Petroleum Year Book, 1914."

Baumé Gravity and Corresponding Specific Gravities, Weights per Gallon and Calorific Power of Oil[1]

Baumé°	Specific gravity	Pounds in a gallon	Calculated B.t.u. per pound	Calculated B.t.u. per gallon	Remarks
14	0.9722	8.10	18,810	152,361	Mexico, California, Texas and Kansas crudes, fuel oil
15	0.9655	8.05	18,850	151,743	
16	0.9589	7.99	18,890	150,931	
17	0.9523	7.94	18,930	150,304	
18	0.9459	7.88	18,970	149,484	
19	0.9395	7.83	19,010	148,848	
20	0.9333	7.78	19,050	148,209	
21	0.9271	7.73	19,090	147,506	
22	0.9210	7.68	19,130	146,918	
23	0.9150	7.63	19,170	146,267	
24	0.9090	7.58	19,210	145,612	
25	0.9032	7.54	19,250	145,145	
26	0.8974	7.49	19,290	144,482	
27	0.8917	7.44	19,330	143,815	
28	0.8860	7.39	19,370	143,144	Kansas, Indian Territory and Illinois crudes, Penn'a. fuel, California refined fuel oil
29	0.8805	7.34	19,410	142,469	
30	0.8750	7.29	19,450	141,790	
31	0.8695	7.25	19,490	141,303	
32	0.8641	7.21	19,530	140,811	
33	0.8588	7.16	19,570	140,121	
34	0.8536	7.12	19,610	139,623	
35	0.8484	7.07	19,650	138,926	
36	0.8433	7.03	19,690	138,421	
37	0.8383	6.99	19,730	137,913	Ohio, Penn'a. and West Virginia crude, California and Kansas refined fuel oil
38	0.8333	6.95	19,770	137,402	
39	0.8284	6.91	19,810	136,887	
40	0.8235	6.87	19,850	136,370	
41	0.8187	6.83	19,890	135,849	
42	0.8139	6.80	19,930	135,524	
43	0.8092	6.76	19,970	134,997	
44	0.8045	6.72	20,010	134,467	
45	0.8000	6.68	20,050	133,934	
46	0.7954	6.64	20,090	133,398	Kerosene and gasoline
47	0.7909	6.60	20,130	132,858	
48	0.7865	6.57	20,170	132,517	
49	0.7821	6.53	20,210	131,971	
50	0.7777	6.49	20,250	131,423	

[1] From "Fuel Oil Data," Tate-Jones & Co., Inc., furnace engineers, based on Sherman and Krapff's formula:

$$\text{B.t.u.} = 18{,}650 - 40\ (\text{Bé.}^\circ - 10)$$

Journ. Am. Chem. Soc., October, 1908.

LIMITS OF FUEL ANALYSES—UNITED STATES[1]

	H_2O	Ash	Sulphur	C	H	O + N	Calories
Peat	6.00–19.7	3.2–36.0	0.19–1.94	....	....	....	2867–5161
Brown coal	5.8 –14.0	1.7–14.7	0.63–2.20	53–70	3.6–7.4	10.8–23.9	4700–6000
Bituminous	0.6 – 5.2	6.1–14.7	0.90–4.5	60.5–78.8	4.8–5.2	9.1–15.4	6000–8000
Anthracite	0.5 – 2.5	1.0– ?	....	91–98	0.0–3.0	0.0–3.0	7000
Coke[2]	0.15–1.2	3.8–11.5	0.6–1.6	87–93	0.4–3.0	....	....

[1] SOMERMEIER'S "Coal."
[2] Compressive strength of 600–2000 lb. per square inch, hardness of 2.5–3. These values from private notes on Eastern cokes.

TYPICAL GAS ANALYSES[1]

	CO	Vol. hyd. carb.	N	CO_2	H
Producer gas	23.7–33.6	1.3 –11.9	49.5–67.1	0.45– 5.30	1.25– 9.7[2]
Mond gas	10.3–11.0	2.0 – 5.3	43.0–55.8	14.6 –16.5	23.5 –27.5
Iron-furnace gas	20.0–32.0	0.0 – 0.6	55.0–65.0	6.0 –18.0	1.0 – 6.0
Water gas (blow up)	23.7–32.2	0.18– 0.44	63.9–65.9	1.6 – 7.0	2.1 – 2.95
Water gas (true)	40.9–45.2	0.2 – 1.1	1.9– 7.1	1.8 – 5.6	44.8 –51.4
Oil gas	0.6– 1.8	28.5 –77.3	0	1.3	18.9 –68.5

[1] HOFMAN'S "General Metallurgy."
[2] Using steam.

Oxygen and Air Required for Perfect Combustion[1]

1 kilogram	Requires kilograms		Product of combustion		Nitrogen in original air kilograms
	Oxygen	Dry air	Composition	Kilograms	
C	1.333	5.777	CO	2.333	4.444
C	2.667	11.555	CO_2	3.667	8.888
CO	0.571	2.472	CO_2	1.571	1.901
H	8.000	34.664	H_2O	9.000	26.664
CH_4	4.000	17.332	CO_2, H_2O	2.750, 2.250	13.332
C_2H_4	3.429	14.848	CO_2, H_2O	3.143, 1.286	11.419
Fe	0.286	1.238	FeO	1.286	0.952
Fe	0.429	1.857	Fe_2O_3	1.439	1.428
Si	1.143	5.064	SiO_2	2.143	3.921
P	1.290	5.586	P_2O_5	2.290	4.296
Mn	0.291	1.221	MnO	1.291	0.969
S	1.000	4.333	SO_2	2.000	3.333

Theoretical Maximum Combustion Temperatures[2]

Oxyhydrogen flame	3191°C.
Hydrogen and dry air	2010°C.
Hydrogen and dry air in 25 per cent. excess	1764°C.
Carbon monoxide with cold air	2050°C.
CO and air, both at 700°C	2284°C.
Natural gas and air	1806°C.
Natural gas with air at 1000°C	2288°C.
Thermit (2Al + Fe_2O_3)	2694°C.

Comparative Composition of Different Fuels[3]

Moisture Content when New

Fuel	Moisture, per cent.	Remarks
Wood	30–60	Green wood.
Peat	50–90	As dug.
Lignite	30–45	As mined.
Bituminous coal	2–25	As mined.
Semi-bituminous coal	1– 5	As mined.
Anthracite coal	1– 3	As mined.

[1] From Hofman's "General Metallurgy."
[2] J. W. Richard's "Metallurgical Calculations," Vol. I, pp. 36–39.
[3] Somermeier's "Coal."

Composition and Heating Value of Air-dried Materials

	Wood	Peat[1] Florida	Lignite,[2] North Dakota	Bituminous: Illinois[2]	Bituminous: Ohio,[3] Hocking	Penna.,[4] Pittsburgh	Semi-bit.,[2] New River	Anthracite,[2] Penna.
Proximate								
Moisture	20.00	21.00	16.70	5.13	3.00	1.00	0.76	2.08
Volatile	......	51.72	37.10	32.68	39.00	35.00	20.54	7.27
Fixed carbon	......	22.11	39.49	47.46	50.50	57.85	73.61	74.32
Ash	......	5.17	6.71	14.73	7.50	6.15	5.09	16.33
		100.00	100.00	100.00	100.00	100.00	100.00	100.00
Ultimate								
Carbon	40.0	46.57	55.16	60.51	70.70	78.75	82.41	75.21
Hydrogen	7.2	6.51	5.61	4.88	5.20	5.14	4.38	2.81
Nitrogen	0.8	2.33	0.91	1.23	1.30	1.55	1.05	0.80
Oxygen	50.7	38.97	30.98	14.20	11.95	7.56	5.87	4.08
Sulphur	......	5.17	0.63	4.45	3.35	0.90	1.20	0.77
Ash	1.3	0.45	6.71	14.73	7.50	6.10	5.09	16.33
	100.0	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Determined Calorific value	4200	4515	5273	6199	7155	7865	8254	6929
Calculated Calorific value	......	4338	5071	6059	7100	7845	7942	6886

[1] U. S. G. S., "Bulletin No. 332."
[2] U. S. G. S., "Professional Paper, No. 48."
[3] Ohio G. S., "Bulletin No. 9."
[4] U. S. G. S., "Bulletin No. 290."

Ultimate Composition of Crude Oils and Coal[1]
Crude Oil

	Sp. gr.	C	H	O
Pennsylvania	0.886	84.9	13.7	1.4
Russia (Balachny)	0.884	87.4	12.5	0.1
Russia (Balachny residuum)	0.928	87.1	11.7	1.2
Borneo	0.945	87.8	10.78	1.24
Texas	0.936	85.66	11.03	3.31
Burma	0.920	86.4	12.1	1.5

[1] From "The Petroleum Year Book, 1914."

Mineral Oils—General Composition[1]

The characteristics of crude mineral oils and their products vary greatly in different localities; but the following general information may be of interest.

	Gravity, deg. Bé.	Flash point, deg. F.	Burning point, deg. F.
Crude oil	12–45	110–200	120–220
Kerosene	40–50	90–125	105–150
Distillate (gas oil)	28–38	100–250	110–325
Fuel oil	22–28	100–300	125–375
Residuum	10–20	125–500	200–600

The heat value of mineral oils and their products may be very closely determined from their gravity, by the following formula:

$$\text{B.t.u. per pound} = 18{,}650 + \{40(\text{Baumé} - 10)\}$$

(Sherman and Krapff)

Coal[2]

	Sp. gr.	C	H	O	S	Ash	H_2O
Welsh	1.315	83.8	4.8	1.0	1.4	4.1	4.9
Newcastle	1.256	82.1	5.3	1.3	1.2	5.7	3.8
Lancashire	1.273	77.9	5.3	1.3	1.4	9.5	4.6

Commercial Sizes of Anthracite

Grade	Size of screen, inches		Wt. per cu. ft., lb.	1 cu. ft. solid coal gives, cu. ft.
	On	Through		
Lump	4½ –9	....	57.0	1.614
Broken	2⅜ –2⅞	3¼ –4½	53.0	1.755
Egg	1¾ –2¼	2⅜ –2⅞	52.0	1.769
Large stove	1¼ –1⅞	1¾ –2¼	51.5	1.787
Small stove	1 –1¼	1¼ –1½	51.25	1.795
Chestnut	⅝ – ¾	1 –1¼	51.00	1.804
Pea	⅜ – ⅝	⅝ – ⅞	50.75	1.813
No. 1 Buckwheat	3/16 – ⅜	⅜ – ⅝	50.75	1.813
No. 2 Buckwheat	....	3/16 – ⅜	50.75	1.813

Shale Oil

These oils are secured by the distillation of shales. Two typical shale analyses are given by Sexton as follows: (1)

[1] "The Diesel Engine," Busch-Sulzer Bros., Diesel Engine Co.
[2] "Petroleum Year Book," 1914.

Volatile matter, 34.96 per cent.; fixed carbon, 7.54 per cent.; ash, 57.5 per cent. (2) Volatile matter, 13.5 per cent.; fixed carbon, 2.5 per cent.; ash, 84 per cent.[1]

TYPICAL GAS ANALYSES[1] (BY VOLUME)

	Natural gas	Coal gas	Producer gas	Water gas	Mond gas
Hydrogen	4.8	51.8	8.0	49.17	27.2
Carbon monoxide	0.2	9.1	23.7	43.75	11.0
Marsh gas	53.7	31.8	2.2	0.31	1.8
Olefines	41.2	5.2	....	....	0.4
Nitrogen	0.1	2.1	61.5	4.00	42.5
Carbon dioxide	....	....	4.1	2.71	17.1

KINDLING TEMPERATURES OF FUELS[2]

Solid	Deg. C.	Gaseous	Oxygen	Air
Dry peat	225	Hydrogen	585	580–590
Bituminous coal	326	Carbon monoxide, moist	651	644–658
Pine wood	395	Ethylene	543	542–547
Charcoal, made at 350°C.	360	Acetylene	429	406–440
		Hydrogen sulphide	364	....
Charcoal, made at 1250°C.	650	Methane	650–750	650–750
		Ethane	520–630	....
Anthracite	700	Benzene	....	406–440
Coke	700	Illuminating gas	....	580–590
Mine timbers	200–400	Water gas	....	644–658
Lignite dust	150	Enriched producer gas	....	644–658
		Propane	547	....
		Propylene	504	....
		Cyanogen	810	850–862

Calorific Power of Fuels

Let H represent the percentage of hydrogen in a fuel; C represent the percentage of carbon; O the oxygen; S the sulphur; and assume also that the water formed by the combustion, represented by H_2O, does not condense (which it usually does not in metallurgical operations).

DULONG'S formula for calorific power of a fuel then is:

$$C.P. = \frac{8{,}100C + 34{,}500\left(H - \frac{O}{8}\right) + 2{,}250S - 537H_2O}{100}$$

An empirical formula adopted by German engineers is:

$$C.P. = \frac{8{,}100C + 29{,}000\left(H - \frac{O}{8}\right) + 2{,}500S - 600H_2O}{100}$$

[1] SEXTON, "Fuel and Refractory Materials."
[2] DIXON and COWARD, "*Journ. Chem. Soc. of London*," 1910, p. 514.

Fractions of Average Coal Tar and Their Uses[1]

First crude separation by distillation.	Light oil.	Middle oil (or dead oil).	Heavy oil (including anthracene oil).	Pitch.
Temperatures of distillation.	70°–160°C.	160°–230°C.	230°–360°C.	Above 360°C.
Percentage in tar.	3	8	24	65
Intermediate products, by distillation or expression.	Benzene, toluene, xylene, etc.; phenol.	Phenol, cresols, etc.; naphthalene, heavy hydrocarbons	Cresols, naphthalene, anthracene; heavy hydrocarbons quinoline bases.	Soft pitch, hard pitch.
Crude commercial products and their uses.	"Benzol" and solvent naphtha for solvents, paint thinners, motor fuel, gas enrichment.	Creosote oil. Lamp black. Disinfectants.	Road oils, impregnation of timber. Roofing tars. Paving tars.	Pitch, briqueting, protective paints.
Intermediate chemical products.	Nitrobenzene, aniline salts, aniline oil, carbolic acid.	Carbolic acid, picric acid, phthalic acid, naphthols, naphthylamines, salicylic acid.	Anthraquinone, alizarin.	
Refined chemical products, dyes, etc., and their uses.	Nitrotoluenes, diphenylamine and other ingredients of explosives; aniline dyes; hydroquinone and other photographic developers; drugs and medicines.	Picric acid, picrates, and other nitro-compounds for explosives; naphthol dyes and colors, artificial indigo, refined carbolic acid.	Alizarin dyes.	

Inflammability of Gaseous Mixtures—Determination of the Dilution Limits.[2]—The results given by previous workers varied over a considerable range. The authors define a gaseous mixture as inflammable at a stated temperature and pressure if it will propagate flame indefinitely when the unburnt portion of the mixture is kept at that temperature and pressure. Combustion in an inflammable mixture is not necessarily complete. In order to conform to this definition, the flame is started near the bottom of a tall vessel which is of sufficient cross-section to minimize the cooling influence of the walls, and the bottom of the vessel is sealed in water so that the pressure cannot rise appreciably. Upward flame propagation is adopted since in very weak mixtures the velocity of propagation may be less than that of the upward convection currents and downward propagation of the flame may thus be prevented. Under these conditions the following minima were found:

[1] Tech. Paper 89, Bureau of Mines.
[2] H. F. Coward and F. Brinsley, *Chem. Soc. Trans.*, 1914, **105**, 1859–1885.

Lowest Limits for Hydrogen, Methane and Carbon Monoxide in Air.—Mixtures at atmospheric pressure, and saturated with water vapor at 17°–18°C., were inflammable if they contained not less than 4.1 per cent. H_2, 5.3 per cent. CH_4, or 12.5 per cent. CO.

COMPOSITION OF THE RESIDUAL ATMOSPHERE PRODUCED BY FLAMES[1]

Substance burnt	Composition of residual atmosphere in which flame was extinguished		
	O_2, per cent.	N_2, per cent.	CO_2, per cent.
Alcohol	14.9	80.7	4.35
Methylated spirit	15.6	80.2	4.15
Paraffin oil	16.6	80.4	3.0
Colza and paraffin	16.4	80.5	3.1
Candles	15.7	81.1	3.2
Hydrogen	5.5	94.5	....
Carbon monoxide	13.4	74.4	12.2
Methane	15.6	82.1	2.3
Coal gas	11.4	83.7	4.9

LIMITS OF COMBUSTION (GAS AND AIR)[2]

	Lower explosive limit, per cent.[3]	Other authors	Upper explosive limit, per cent.[3]	Other authors
Carbon monoxide	16.00	13–16.7	74.95	74.1–77.5[5]
Hydrogen	9.45	4.5–10	66.40	55–80[5]
Water gas	12.40	....	66.75	....
Acetylene	3.35	2.8–3.35	52.30	52.3–80[5]
Coal gas	7.90	4.5–8.1	19.10	18.4–30[5]
Methane	6.10	4–7.7	12.80	12.8–16.7[5]
Gasoline	2.40	1.62[6]	4.90	6.0[6]
Ethylene	4.10	3.5–4.1	14.6	11.8–22[5]
Hydrogen[4]	9.1	4.4–13	....	91–96.7[5]

Coal Burned per Square Foot of Grate in Reverberatory Furnaces[7]

Hand reverberatory roasting furnace	3 to 8 lb.
Agglomerating or lead-reverberatory smelting furnace	12 to 16 lb.
Copper-reverberatory smelting furnace	16 to 30 lb.

[1] *Journ. Soc. Chem. Ind.*, Feb. 27, 1915.
[2] From BENSON'S "Industrial Chemistry." The Macmillan Co.
[3] Eitner's values.
[4] With oxygen.
[5] It is evident that the various observers have not standardized conditions.
[6] Bureau of Mines, 1915. Probably most reliable figures given.
[7] GRÜNER, "Traité de Metallurgie Générale."

Puddling furnace	20 to 30 lb.
Heating furnace	30 to 40 lb.
Locomotive boilers (induced draft)	80 to 100 lb.

Ratio of Areas of Total Grate to Air Space[1]

Coke	3:1 to 2:1
Bituminous coal	3:3:1 to 2:1
Brown coal	5:1 to 3:1
Peat or wood	7:1 to 5:1

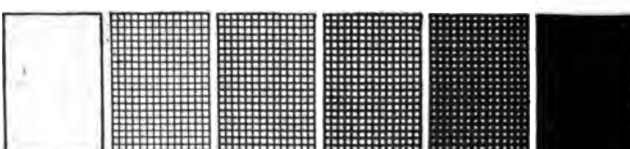
Combustion Data

Good modern practice

1 lb. coal average	13,500 B.t.u.
1 lb. coal $(13{,}500 \times 778) \div (60 \times 33{,}000)$	5.3 hp.-hours.
Lost through grates	1.00 per cent.
Lost boiler radiation	5.00 per cent.
Lost chimney gases	22.00 per cent.
Lost main pipes radiation	1.56 per cent.
Lost auxiliary pipes radiation	0.22 per cent.
Lost auxiliary exhaust	1.40 per cent.
Lost engine radiation	2.08 per cent.
Lost engine exhaust	57.31 per cent.
Total loss	90.57 per cent.
Converted to power	9.43 per cent.

Ringelmann's Smoke Chart

The following chart is convenient for estimating the density of smoke from chimneys, both as a check on the completeness of combustion and as evidence in case certain chimneys are attacked as nuisances by owners of property near metallurgical

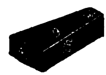


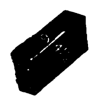
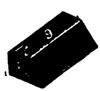
plants. (Use this chart at arms length. The original is a chart 3 × 24 in., supposed to be posted about 50 ft. away.)

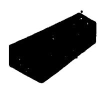
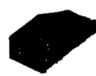
[1] Leitfader to Eisenhüttenkunde, 1898, p. 104.

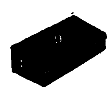
Standard Fire Brick Shapes[1]

Name	Dimensions
9 in.	9 × 4½ × 2½
Soap	9 × 2½ × 2¼
No. 1 Split	9 × 4½ × 1¼
No. 2 Split	9 × 4½ × 2
9-in. large	9 × 6¾ × 2½
9-in. small	9 × 3½ × 2½
No. 1 Key	9 × 4½ – 4 × 2½ : 12 ft. diam. inside. 112 brick to circle.
No. 2 Key	9 × 4½ – 3½ × 2½ : 6 ft. diam. inside. 65 brick to a circle.
No. 3 Key	9 × 4½ – 3 × 2½ : 3 ft. diam. inside. 41 brick to a circle.
No. 4 Key	9 × 4½ – 2¼ × 2½ : 18 in. diam. inside. 26 brick to a circle.
No. 1 Wedge[2]	9 × 4½ × 2½ – 2 : 5 ft. diam. inside. 102 brick to a circle.
No. 2 Wedge[2]	9 × 4½ × 2½ – 1½ : 2 ft. 6 in. diam. inside. 63 brick to a circle.
No. 1 Arch	9 × 4½ × 2½ – 2 : 4 ft. diam. inside. 72 brick to a circle.
No. 2 Arch	9 × 4½ × 2½ – 1½ : 2 ft. diam. inside. 42 brick to a circle.
No. 3 Arch	9 × 4½ × 2½ – 1 : 6 in. diam. inside. 19 brick to a circle.
Side Skew	9 × 4½ – 1¾ × 2½
End Skew	9 × 7 × 4½ × 2½
Skewback	9 × 4½ – 1½ × 2½
No. 1 Neck	9 – 4½ × 4½ × 2½
No. 2 Neck	9 – 2 × 4½ × 2½
No. 3 Neck[2]	9 × 4½ × 2½ – ⅝
Feather edge	9 × 4½ × 2½ – ⅛
No. 1 Jamb	9 × 4½ × 2½ (rounded corner).
No. 2 Jamb	9 × 4½ × 2½ (rounded corner and beveled corner).
No. 3 Jamb	9 × 4½ × 2½ (rounded corner).
No. 3 Bullhead[2]	9 × 4½ × 3 – 2 (see illustration).
Checker	9 × 3 × 3 or 9 × 2¾ × 2¾.
Large 9 in. No. 1 Wedge	9 × 6¾ × 1⅞ : 5 ft. diam. inside. 102 brick to the circle.
Large 9-in. No. 2 Wedge	9 × 6¾ × 2½ – 1½ : 2 ft. 6 in. diam. inside. 63 brick to the circle.
Edge arch	9 × 4½ – 3 × 2½.
Checker tile	18 (or 20 or 24) × 6 × 3.
Checker tile (mill tile)	18 (or 20 or 24) × 9 × 3.






[1] As made by the Stowe-Fuller Co., Cleveland, Ohio. Other makers deviate slightly from the figures given for keys.

[2] The wedge brick taper from end to end, as do the keys, No. 3 neck, and bullhead.

Table of Firebrick for Various Circles[1]

Inside diameter of circle		Arch bricks				9-in. key bricks						Wedge bricks				13½-in. key bricks			
Ft.	In.	No. 2 arch	No. 1 arch	9 in.	Total	No. 4 key	No. 3 key	No. 2 key	No. 1 key	9-in.	Total	No. 2 wedge	No. 1 wedge	9-in.	Total	No. 2 wedge	No. 1 wedge	Straights	Total
1	6	...	...	...	...	25	...	...	...	...	25	...	...	...	...	...	...	...	...
2	0	42	...	...	42	17	13	...	...	...	30	60	...	...	60	...	...	...	...
2	6	10	40	...	50	9	25	...	...	...	34	48	20	...	68	...	...	...	...
3	0	...	57	...	57	...	38	...	...	...	38	36	40	...	76	...	...	...	...
3	6	...	57	7	64	...	32	10	...	...	42	24	59	...	83	...	...	...	...
4	0	...	57	15	72	...	25	21	...	...	46	12	79	...	91	...	...	...	...
4	6	...	57	22	79	...	19	32	...	...	51	...	98	...	98	...	...	...	...
5	0	...	57	29	86	...	13	42	...	...	55	...	98	8	106	...	...	...	...
5	6	...	57	37	94	...	6	53	...	...	59	...	98	15	113	...	...	...	...
6	0	...	57	44	101	...	...	63	...	...	63	...	98	23	121	53	...	...	53
6	6	...	57	52	109	...	...	58	9	...	67	...	98	30	128	52	5	...	57
7	0	...	57	59	116	...	...	52	19	...	71	...	98	38	136	48	12	...	60
7	6	...	57	67	124	...	...	47	29	...	76	...	98	46	144	42	21	...	63
8	0	...	57	74	131	...	...	42	38	...	80	...	98	53	151	36	30	...	66
8	6	...	57	82	139	...	...	37	47	...	84	...	98	61	159	30	40	...	70
9	0	...	57	89	146	...	...	31	57	...	88	...	98	68	166	24	49	...	73
9	6	...	57	97	154	...	...	26	66	...	92	...	98	76	174	18	58	...	76
10	0	...	57	104	161	...	...	21	76	...	97	...	98	83	181	12	67	...	79
10	6	...	57	112	169	...	...	16	85	...	101	...	98	91	189	8	74	...	82
11	0	...	57	119	176	...	...	11	94	...	105	...	98	98	196	6	79	...	85
11	6	...	57	127	184	...	...	5	104	...	109	...	98	106	204	4	84	...	88
12	0	...	57	134	191	...	...	...	113	...	113	...	...	...	...	...	91	...	91
12	6	...	57	142	199	...	...	...	113	4	117	...	...	...	...	...	91	3	94
13	0	...	...	...	...	...	...	...	113	9	122	...	...	...	...	...	91	6	97
13	6	...	...	...	...	...	...	...	113	13	126	...	...	...	...	...	91	9	100
14	0	...	...	...	...	...	...	...	113	17	130	...	...	...	...	...	91	13	104
14	6	...	...	...	...	...	...	...	113	21	134	...	...	...	...	...	91	16	107
15	0	...	...	...	...	...	...	...	113	26	139	...	...	...	...	...	91	19	110
16	0	...	...	...	...	...	...	...	113	34	147	...	...	...	...	...	91	25	116

[1] From the Stowe-Fuller Co.'s catalog.

Hints on Brick Laying

One ton of fire-clay ought to lay about 6000 brick. The composition in which they are laid should be, if possible, of the same composition as the brick themselves, and the brick should be dipped in a thin paste and laid, not laid in a mortar. In general, the thinner the bond between the bricks the better the work. The joints are the zones of greatest weakness and are soonest attacked. For metallurgical furnaces it appears that the denser the brick the less its absorption. Magnesite brick are best laid in a suspension of finely ground magnesite in anhydrous tar, or magnesite and linseed oil, or in a suspension of magnesite in a 20 per cent. sodium silicate solution. Silica brick are best laid in a thin paste of 60 fine sand, 40 fire-clay. About $\frac{5}{32}$ in. per foot should be left for expansion in a furnace bottom.

Always store Refractories in a Dry Place

Magnesite bricks are good conductors of heat, and where this conductivity would injure the armoring of the furnace, the brick should be backed by asbestos or some other non-conductor. Great variations of temperature, or heating when they are moistened with water or oil, will cause spalling. Magnesite brick should not be subjected to great loads when hot.

For red-brick work 9 cu. ft. of sand and 3 bu. of lime will lay 1000 brick.

Brickwork Table[1]

1 sq. ft. of $4\frac{1}{2}$-in. wall requires seven bricks.
1 sq. ft. of $13\frac{1}{2}$-in. wall requires twenty-one bricks.
1 cu. ft. of brickwork requires seventeen 9-in. bricks.
1 cu. ft. of fire-clay brickwork weighs 150 lb.
1 cu. ft. of silica brickwork weighs 130 lb.
1000 bricks (closely stacked) occupy 56 cu. ft.
1000 bricks (loosely stacked) occupy 72 cu. ft.

M. S. Wologdine has probably done the best work on the thermal properties of fire brick. A. L. Queneau deduces, among others, the following conclusions from Wologdine's work:

1. All terra cotta, building bricks and fire bricks have practically equal coefficients of heat conductivity. The coefficients are differentiated in this class of refractory materials solely by the temperature of burning and not by the character of the clays or by their chemical composition.
2. In all refractory materials, including the special bricks, such as chrome, magnesia, carborundum and graphite, the heat conductivity is a direct function of the temperature of burning.
3. The coefficient of heat conductivity of chrome brick is practically independent of the temperature.
4. There are remarkable variations in the permeability to gases of the same bricks with increase in temperature. In one case the permeability changed from 3.3 liters per hour to

[1] Havard, "Furnaces and Refractories."

241 liters per hour. This shows the importance of scientifically selecting the clay mixtures for a given work as for crucibles or retorts where, as in zinc metallurgy, the permeability to gases has a material influence on the metal recovery. In this connection the nil permeability of graphite crucibles is to be noted. Perhaps the same results might be obtained at a much reduced cost by substituting clay flakes for the graphite flakes proposed by H. Putz (German pat. 198,840 of Sept. 29, 1907).

5. To secure efficient heat insulation, refractory materials should be burned at the lowest allowable temperature. This burning temperature is generally known; it is the maximum temperature to which the bricks will be exposed in the furnaces. The use of the maximum temperature is necessary in order to prevent the brick from shrinking any further when set in the furnace walls. Though this last fact is well known it is often neglected, and a shortening of the furnace life is the result.

6. The gas permeability of the bricks of blast-furnace linings must have an important bearing on their life, owing to the destructive action of carbon monoxide in contact with the iron oxide present in the brick.

There is no question that the absorption of metals by a furnace bottom will be directly proportional to the air spaces in the original brick; consequently in work with any of the non-ferrous metals, the nearer the ratio of the specific gravity of the brick in bulk to the true specific gravity of the constituent material approaches unity, the better the brick.

Short Description of the Common Refractories

Alundum.—Melting point, 2050°C.; specific heat, 0.195–0.198 at 100°C.; thermal conductivity about twice that of fire brick. Electric resistivity, at 528°C., 130 megohms per cc.; at 730°, 16 megohms; at 892°, 5.3 megohms; at 1020°, 1.8 megohms. Coefficient of expansion, 0.0000071 per deg. C.; maximum crushing strength, 7½ tons per square inch; tensile strength, 1700 lb. per square inch. Specific gravity, 3.91.

Asbestos.—A very poor conductor of heat and refractory, but will not stand molten slags. The composition of a typical Canadian asbestos is: MgO, 40.07; FeO, 0.87; Al_2O_3, 3.67; SiO_2, 39.05, H_2O, 14.48; total 98.14%.

Bauxite.—Bauxite melts at 1820°C., but as bauxite shrinks about 30 per cent. and crumbles in calcining, some silica must be added to make a good brick. The washed bauxite is calcined at from 1350° to 1400°, ground, pugged with about 4 per cent. of a highly aluminous plastic clay, balled, dried and calcined. The mixture is then ground, pugged again with clay and hand molded. Basic open-hearth brick should not contain over 12 per cent. of silica. An analysis of an American bauxite brick is: SiO_2, 2 per cent.; TiO_2, 5 per cent.; Al_2O_3, 90.5 per cent.; Fe_2O_3, 1 per cent.; and CaO, 1.5–2 per cent. The crushing strength may be as high as 10,000 lb. per square inch, but in general the bricks are weak.

Bull Dog.—This is a mixture of ferric oxide and silica made by roasting tap cinder with free access of air. Tap cinder is a

basic ferrous silicate—$2FeO \cdot SiO_2$ or thereabouts—and on roasting it takes up oxygen, and gives a mixture of ferric oxide and silica. As these do not unite, the substance is infusible in an oxidizing atmosphere, but fuses in a reducing atmosphere, ferrous silicate being re-formed.[1]

Carbon brick—lay in a mixture of tar and carbon dust.

Chrome.—Typical chromites used for refractories analyze as follows (*Eng. and Min. Journ.*, Oct. 24, 1908): Turkish: Cr_2O_3, 51.70 per cent.; FeO, 14.20; Al_2O_3, 14.10; MgO, 14.30; SiO_2, 3.50; CaO, 1.70; H_2O, 0.30 per cent.; New Caledonian: Cr_2O_3, 55.70 per cent.; FeO, 16.60; Al_2O_3, 18.20; MgO, 9.80; SiO_2, 0.25; CaO, 0.25; MnO, 0.20; P_2O_5, 0.05; H_2O, 1.05 per cent.; Japanese: Cr_2O_3, 44.55 per cent.; FeO, 15.25; SiO_2, 5.4; CaO, 0.20; MgO, 19.10; Al_2O_3, 15.20; H_2O, 0.30 per cent. Chrome is unreliable above 1500°C.

Conducts heat two to four times as well as clay brick. Makes a good breaking joint between magnesite and silica. Should be used as little as possible in furnace bottoms on lead, copper, silver, or gold work, as the cobbing is almost impossible either to grind or to smelt. It is not so strong as alumina, nor so resistant to high temperatures.

Clay Brick.—Probably as fine a quality of clay brick is needed in the shafts of iron furnaces as anywhere. Two typical bricks for this purpose are given by Havard as follows: (1) Loss on ignition, 0.07; SiO_2, 54.44; Fe_2O_3, 2.53; Al_2O_3, 40.01; CaO, 0.18; MgO, 0.53; K_2O, 2.24. Crushing strength, pounds per square inch, side, 5098; edge, 3840; end, 2693. Specific gravity, true, 2.34; in mass, 2.03. Porosity, 12.93 per cent. of volume. Expansion, 0.042 in. per foot. (2) Loss on ignition, 0.07; SiO_2, 56.07; Fe_2O_3, 3.32; Al_2O_3, 39.00; CaO, 0.12; MgO, 0.18; K_2O, 1.30. Crushing strength, pounds per square inch, side, 5248; edge, 2170; end, 2710. Specific gravity, true, 2.43; in mass, 2.10. Porosity, 13.30 per cent. of volume. Expansion, 0.064 in. per foot.

Some Typical Refractories Analyses

	Al_2O_3	SiO_2	MgO	CaO	Fe_2O_3	K_2O	Na_2O	TiO_2	Loss	Total
Briesen clay	39.93	44.88	0.08	0.21	0.99	0.52	....	...	13.41	100.07
Saaran clay	36.75	49.00	0.56	....	0.80	0.41	0.37	...	11.87	99.76
Striegau clay	29.65	53.02	0.78	1.15	3.40[2]	0.55	....	...	10.91	99.46
American fire brick	32.07	62.20	0.65	0.70	4.01	....	....	...	......	......
Clay for open hearth	42.12	44.00	0.10	0.24	0.86	....	....	...	14.20	......
N. J. clay for zinc retorts	37.50	45.00	0.30	1.00	0.70	0.50	....	1.5	13.50	......
Missouri clay for zinc retorts	34.46	49.5	0.62	0.80	2.39	....	....	...	12.86	......

[1] Sexton, "Fuel and Refractory Materials."
[2] FeO.

A general formula for determining how refractory a clay is, is given by BISCHOF (cf. HAVARD'S "Furnaces and Refractories," p. 61). If Q be the refractory coefficient, a the oxygen content of the alumina, b that of the silica, and c that of the fluxes, then

$$Q = \frac{a^2}{bc}$$

If Q is between 2 and 4 the clay will make a third-grade fire brick; if between 4 and 6, a second-grade fire brick; from 6 to 14, a first-class fire brick.

Crystolon.—Crystallized silicon carbide (SiC)—does not fuse at 2700°C. Conducts heat a little better than alundum (*q.v.*). Electric resistivity, at 320°C., 31.8 megohms per cc.; at 650°C., 6.3 megohms; at 809°C., 3.2 megohms; at 940°C., 1.0 megohms; at 1040°C., 0.4 megohms. It is not affected by acids or acid vapors, except hydrofluoric, but reacts readily with alkalis, alkaline carbonates and alkaline sulphates, and, at elevated temperatures, with the oxides of practically all metals. Coefficient of expansion, 0.0000045 per deg. C.

Dinas brick—a classic English brick made in South Wales. Composition: SiO_2, 96.80 per cent.; Al_2O_3, 0.92; Fe_2O_3, 0.50; CaO, 1.20; alkalis, 0.20. It is essentially a silica brick with lime as a binder. In America this is known as ganister.

Dolomite.—Analyses of typical dolomites (from HARBORD'S "Steel," p. 212) are: Raw, SiO_2, 1.10 per cent.; Fe_2O_3 and Al_2O_3, 1.64; CaO, 33.20; MgO, 19.60; CO_2, 44.30 per cent. Calcined, SiO_2, 3.66 per cent.; Fe_2O_3 and Al_2O_3, 4.80; CaO, 55.50; MgO, 34.83; CO_2, 1.06 per cent.

Fibrox—a fibrous silicon oxycarbide, formed in the presence of certain catalytic agents, of which calcium fluoride is one, by the reaction between vapors of silicon and carbon monoxide or dioxide. It is a soft, resilient, fibrous material, the average diameter of the fibers being stated by E. WEINTRAUB of the General Electric Co. as being about 0.6μ, or about the wave

Density	Temperature	Thermal ohms	
		R' in. cube	R cm. cube
0.231	200	950	2375
0.231	500	520	1300
0.412	200	1200	3000
0.412	500	605	1510
0.767	200	1320	3300
0.767	500	878	2195
1.27	200	1460	3650
1.27	500	987	2470
1.98	200	1590	3975
1.98	500	1000	2500

length of yellow light, or about one-twentieth that of fine cotton fiber. Its apparent weight is about 2½ to 3 grams per liter, its real specific gravity about 1.84 to 2.2. It is claimed to be the best heat insulator known. It oxidizes slowly above 1000°C.

The effect of the density on the heat resistivity of fibrox at temperatures of 200° and 500° is shown by the foregoing table:[1]

Ganister—another classic English refractory. A typical analysis, from HARBORD: SiO_2, 94.60 per cent.; Al_2O_3, 1.40; Fe_2O_3, 0.90; CaO, 0.48; MgO, 0.16; alkalis, 0.14; water, 2.60 per cent.

Lime.—FITZGERALD reports that lime fused in the electric furnace may be a very useful refractory. It is a better conductor of heat than ordinary lime. Blocks cut from it resist quick heating followed by sudden cooling. Fused lime resists exposure to moist air remarkably well, hydration being a matter of days.

Magnesite—composition, Federal brick: SiO_2, 1.46 per cent.; Al_2O_3, 1.50; Fe_2O_3, 7.58; CaO, 3.14; MgO, 86.36 per cent.

Conducts heat two to four times as fast as clay brick. Usually laid dry, or in a paste made of magnesite clay and 20 per cent. water-glass solution. Magnesite can only be considered "dead-burned" when the final ignition temperature exceeds 1800°C. The greatest objection to magnesite is its cracking when heated to a high temperature. This is due to its shrinkage; a piece of magnesite heated to 350° may have a density of 3.19, while electrically fused its density will be 3.65.

Silica Sand.—An analysis of the sand used for furnace bottoms in Swansea is (from PERCY): SiO_2, 87.87 per cent.; Al_2O_3, 2.13; Fe_2O_3, 2.72; CaO, 3.79; MgO, 0.21; volatile, 2.60 per cent. Silica melts at 1750°, after softening at 1500° and becoming glassy at 1700°C. It expands on heating and does not return exactly to its former volume. In general, silica brick are highly refractory, porous, of low specific gravity, brittle and hard to cut, poor conductors of heat, inelastic, and not resistant to sudden changes of temperature. The compressive strength is about 1900 to 4000 lb. per square inch. A typical American silica-lime brick analyzed as follows: SiO_2, 93.92 per cent.; Fe_2O_3, 0.79; Al_2O_3, 3.07; CaO, 2.55; MgO, 0.18; porosity, 18.58 per cent. of volume, expansion, 0.188 in. per foot. Another brick gave 0.346 in. per foot expansion.

Siloxicon—a more or less oxidized carborundum, the amorphous crystolon of the Norton Co.

Zirconia—a pure white refractory of a density of about 4.2 and a melting point of about 3000°C. Its first important use was to replace the calcium-oxide cylinders in the DRUMMOND light. Used also in the first WELSBACH experiments. Its heat-conducting power is not over half that of firebrick. Has been used as a lining of a SIEMENS-MARTIN furnace with good results.

[1] From a paper presented at the Atlantic City Meeting, American Electrochemical Society, Apr. 22, 1915.

REFRACTORIES

Melting Points of Some Refractory Oxides[1]

Oxide	Temperature of volatilization	Melting point	Color of melt and sublimate	Furnace used	Remarks
BeO	....	About 2400°	White like porcelain	Cathode ray	Evaporated just before melting.
MgO	About 2000°	2800°(a)	....	Both furnaces	Dissociated into its elements.
CaO	1690°	2572°(a)	....	Cathode ray	....
Al_2O_3	1750°	2050°	Colorless, glassy	Cathode ray	Tendency for melt to crystallize.
La_2O_3	2000°	About 2000°	Clear yellow melt	Cathode ray	Dissociated, forming lower oxide.
ZrO_2	....	2430°	White opaque melt	Cathode ray	Evaporated just before melting and dissociated into its elements.
SnO_2	....	Did not melt	....	Cathode ray	Dissociated, forming lower oxide.
SnO	Red heat	Did not melt	Black sublimate	Cathode ray	....
CeO_2	1875°	Did not melt	Transparent sublimate in crucible	Cathode ray	....
ThO_2	About 2000°	2000°	White opaque sublimate	Cathode ray	....
V_2O_5	Did not evaporate	Did not melt	....	Cathode ray	Dissociated probably to VO_2.
V_2O_3	Red heat	Did not melt	Blue-black sublimate	Cathode ray	....
Ta_2O_5	Did not evaporate	Did not melt	....	Cathode ray	....
MnO	....	1650°	Black	Cathode ray	Melt crystallized.

(a) According to C. W. Kanolt, *Journ. Franklin Inst.*, p. 587, 1913; other determinations according to Tiede and Birnbräuer, *Zeit. anorg. Chem.*, 1914, p. 129.

Fused silica—thermal conductivity high. Melting point, 1430°C. Sp. gr., 2.5–2.6. Specific heat, 0.776. Coefficient of expansion, 0.00000539 per deg. C.

MELTING POINTS OF FIRE BRICK

Alumina	2100°(*e*), softens 1970°C.(*e*)
Alundum	2050°C.(*a*)
Bauxite	1820°C.(*b*)
Bauxite brick	1620–1785°C.(*a*)
Bone-ash cupel	1865° C.(*c*)
Carborundum	Decomposes at 2220° with fusing.(*b*)
Chromite	2050°C.(*a*); 2180°(*b*); 1545°–1730°.(*c*)
Clay brick, 1st class	1555–1740°C.(*a*)
Clay brick, 2d class	1400–1650°C.(*e*)
Diatom nonpareil brick	900°C.(*d*)
Dinas silica	1680° C.(*c*)
Kaolinite (pure)	1740°C.(*b*) 1830°.(*e*)
Lime (CaO)	Softens about 2040°C.(*e*)
Magnesia	2720°C.(*a*), softens about 2500°C.(*e*)
Magnesite brick	2165°C.(*a*), softens about 2000°.C(*e*)
Silica	1700–1705°C.(*a*)
Silicon carbide	2700° + C.(*a*)

(*a*) According to Bureau of Standards.
(*b*) *Bull. Tech. A. et M.*, July, 1913, p. 728.
(*c*) W. H. Patterson, "Brit. Iron and Steel Inst. Carnegie Scholarship Memoirs," No. 6, p. 231, 1914.
(*d*) Information from manufacturers. An insulator, not a refractory.
(*e*) F. T. Havard, "Fuels and Refractories."

Testing Refractory Materials under Load.—The melting point of various clays used in the manufacture of firebrick and retort material was found to be 200°–320°C. lower when the clay was under pressures of 54 to 112 lb. per square inch.

Seger Cones and Their Softening Temperatures[1]

Estimated softening point (deg. C.)	Cone No.	Molecular composition				
		Na_2O	PbO	Al_2O_3	B_2O_3	SiO_2
590	022	0.5	0.5	....	1	2.0
620	021	0.5	0.5	0.1	1	2.2
650	020	0.5	0.5	0.2	1	2.4
680	019	0.5	0.5	0.3	1	2.6
710	018	0.5	0.5	0.4	1	2.8
740	017	0.5	0.5	0.5	1	3.0
770	016	0.5	0.5	0.55	1	3.0
800	015	0.5	0.5	0.6	1	3.2
830	014	0.5	0.5	0.65	1	3.3
860	013	0.5	0.5	0.7	1	3.4
890	012	0.5	0.5	0.75	1	3.5
920	011	0.5	0.5	0.8	1	3.6

SEGER CONES AND THEIR SOFTENING TEMPERATURES[1]

Estimated softening point (deg. C.)	Cone No.	Molecular composition					
		K_2O	CaO	Fe_2O_3	Al_2O_3	B_2O_3	SiO_2
950	010	0.3	0.7	0.2	0.3	0.50	3.50
970	09	0.3	0.7	0.2	0.3	0.45	3.55
990	08	0.3	0.7	0.2	0.3	0.40	3.60
1010	07	0.3	0.7	0.2	0.3	0.35	3.65
1030	06	0.3	0.7	0.2	0.3	0.30	3.70
1050	05	0.3	0.7	0.2	0.3	0.25	3.75
1070	04	0.3	0.7	0.2	0.3	0.20	3.80
1090	03	0.3	0.7	0.2	0.3	0.15	3.85
1110	02	0.3	0.7	0.2	0.3	0.10	3.90
1130	01	0.3	0.7	0.2	0.3	0.05	3.95
1150	1	0.3	0.7	0.2	0.3	......	4.0
1170	2	0.3	0.7	0.1	0.4	......	4.0
1190	3	0.3	0.7	0.05	0.45	......	4.0
1210	4	0.3	0.7	......	0.5	......	4.0
1230	5	0.3	0.7	......	0.5	......	5.0
1250	6	0.3	0.7	......	0.6	......	6.0
1270	7	0.3	0.7	......	0.7	......	7.0
1290	8	0.3	0.7	......	0.8	......	8.0
1310	9	0.3	0.7	......	0.9	......	9.0
1330	10	0.3	0.7	......	1.0	......	10.0

[1] F. T. HAVARD, "Furnaces and Refractories."

Seger Cones and Their Softening Temperatures

Estimated softening point (deg. C.)	Cone No.	Molecular composition			
		K_2O	CaO	Al_2O_3	SiO_2
1350	11	0.25	0.58	1	10.0
1370	12	0.21	0.50	1	10.0
1390	13	0.19	0.43	1	10.0
1410	14	0.17	0.39	1	10.0
1430	15	0.14	0.33	1	10.0
1450	16	0.13	0.29	1	10.0
1470	17	0.11	0.26	1	10.0
1490	18	0.10	0.23	1	10.0
1510	19	0.09	0.20	1	10.0
1530	20	0.08	0.18	1	10.0
[1]	21	0.07	0.15	1	10.0
[1]	22	0.06	0.14	1	10.0
[1]	23	0.06	0.13	1	10.0
[1]	24	0.05	0.12	1	10.0
[1]	25	0.04	0.11	1	10.0
1580	26	0.04	0.10	1	10.0
1610	27	0.02	0.03	1	10.0
1630	28	....	....	1	10.0
[1]	28½	....	....	1	9.0
1650	29	....	....	1	8.0
[1]	29½	....	....	1	7.0
1670	30	....	....	1	6.0
1690	31	....	....	1	5.0
1710[2]	32[2]	....	....	1	4.0
1730	33	....	....	1	3.0
1750	34	....	....	1	2.5
1770	35	....	....	1	2.0
1920	40	....	....	1	....

[1] These cones are not manufactured. as their estimated softening points lie too close to neighboring cones, and are somewhat irregular.

[2] Pure silica behaves like cone 32.

From "The Silicates in Chemistry and Commerce," by W. and D. Asch.

Metallic Salts as Fusion Pyrometers[1]

Salt	Melting point, deg. C.	Salt	Melting point, deg. C.
Na_2SiO_3	1007	KBr	730
K_2SO_4	1070	KI	682
$BaCl_2$	955	5.8KCl + 4.2NaCl	655
K_2SiO_3	890	3NaCl + 7KBr	625
Na_2SO_4	865	$Ba(NO_3)_2$	600
$5K_2SO_4 + 5Na_2SO_4$	850	$5KCl + 5K_2CO_3$	580
$3K_2SO_4 + 7Na_2SO_4$	830	$3Na_2CO_3 + 3K_2CO_3 + 2NaCl + 2KCl$	560
$2K_2SO_4 + 8Na_2SO_4$	825	$Ca(NO_3)_2$	550
Na_2CO_3	810	$3K_2SO_4 + 3Na_2SO_4 + 2NaCl + 2KCl$	520
NaCl	800	NaOH	320
KCl	775	$NaNO_3$	313

[1] Hofman, "General Metallurgy."

Erhard and Schertel Fusion Pyrometers[1]

Composition	Melting point, deg. C.	Composition	Melting point, deg. C.
100Ag	954	60Au 40Pt	1320
80Ag 20Au	975	55Au 45Pt	1350
60Ag 40Au	995	50Au 50Pt	1385
40Ag 60Au	1020	45Au 55Pt	1420
20Ag 80Au	1045	40Au 60Pt	1460
100Au	1075	35Au 65Pt	1495
95Au 5Pt	1100	30Au 70Pt	1535
90Au 10Pt	1130	25Au 75Pt	1570
85Au 15Pt	1160	20Au 80Pt	1610
80Au 20Pt	1190	15Au 85Pt	1650
75Au 25Pt	1220	10Au 90Pt	1690
70Au 30Pt	1255	5Au 95Pt	1730
65Au 35Pt	1285	100Pt	1775[2]

[1] Hofman, "General Metallurgy."
[2] 1755°C. is probably the correct figure.

Color Scales[1]

White and Taylor		Pouillet		Howe	
Name of color	Deg. C.	Name of color	Deg. C.	Name of color	Deg. C.
....	....	....	.....	Lowest visible red in dark..........	470
....	....	Incipient redness.	525	Lowest visible red in daylight......	475
Dark red..........	566	Dark red........	700	Dull red........	550–625
Dark cherry red....	635	Incipient cherry red............	800		
Cherry, full red....	746	Cherry red......	900	Full cherry.......	700
Light cherry, bright cherry, light red...	843	Light cherry red.	1000	Light red.........	850
Orange............	899	Dark orange.....	1100	....	....
Light orange.......	941	Light orange.....	1200	....	....
Yellow............	996	....	.....	Full yellow.......	950–1000
White.............	1205	White..........	1300	White...........	1150
....	....	Brilliant white...	1400	....	....
....	....	Dazzling white..	1500–1600	....	....

[1] Hofman, "General Metallurgy," p. 138.

Loss of Heat by Radiation

(Loss in Gram-calories per Square Centimeter of Surface at100°C. to Surrounding Bodies at 0°C.—Peclet's Figures)

Polished brass.......	0.00108	Russia sheet iron...	0.01410
Copper.............	0.00068	New cast iron......	0.01332
Polished sheet iron...	0.00189	Oxidized iron......	0.01410
Leaded sheet iron....	0.00273	Glass..............	0.01222
Ordinary sheet iron..	0.01164	Building stone.....	0.01500

To correct the above figures for various other ranges of temperature than from 100°C to 0°C., multiply by the factors below.

100°–0°	1.0	600°–0°	26.0
150°–0°	2.0	700°–0°	35.0
200°–0°	3.3	800°–0°	45.3
300°–0°	7.0	900°–0°	57.0
400°–0°	12.0	1000°–0°	70.0
500°–0°	18.3		

In general, radiation from hot bodies to cold surroundings will vary as the differences of the fourth powers of the absolute temperatures.

Heat Emissivity of Various Surfaces[1]

Black body	1.00
Copper, oxidized	0.72
Copper, calorized	0.26
Silver	0.03
Cast iron, bright	0.22
Cast iron, oxidized	0.62
Cast iron, aluminum painted	0.50
Cast iron, gold enamelled	0.37
Monel metal, bright	0.43
Monel metal, oxidized	0.43
Brick surfaces (probably)	0.60–0.75

Diffusivity[2]

Aluminum	0.83	Air	0.18
Antimony	0.14	Cotton	0.0009
Cadmium	0.47	Cork	0.0001
Copper	1.13	Ebonite	0.0001
Bismuth	0.07	Rock material (granite, etc.)	0.012
Gold	1.18		
Iron	0.17	Ice	0.011
Lead	0.24	Concrete	0.006
Magnesium	0.88	Average damp soil	0.0049
Mercury	0.03	Water	0.0014
Nickel	0.15	Fire brick	0.0067
Platinum	0.24	Building brick	0.005
Silver	1.74	Silica	0.003
Cast steel	0.12	Silica brick	0.0053–0.0098
Tin	0.38	Magnesia	0.0126–0.0226
Zinc	0.40		

[1] Boyd Dudley, Jr., "Penn. State Min. Quart.," April, 1915.

[2] The property of diffusing and transmitting heat is dependent on the conductivity, the density and the specific heat of the body. Thus the coefficient of diffusivity, $D = \frac{K}{WS_1}$ where K is the thermal conductivities in gram-calorie-seconds per cm.^{3} per 1°C. F. T. Havard, "Refractories and Furnaces."

CONDUCTIVITY, DENSITY, POROSITY AND PERMEABILITY OF REFRACTORY MATERIALS[1]

Material	Conductivity		Density		Porosity in per cent. of volume	Permeability		Temperature of burning
	Gram-cal. per sq. cm. per hr. per 1°C. difference	Kg.-cal.-hr. per sq. m. per m. per 1°C. difference	True δ	Apparent δ		Cm.^{3} sec. per sq. m. per cm.	Lit.-hr. per sq. m. per m.	
Fire-clay brick	0.0037	1.32	2.61	1.81	30.8	0.0409	14.72	1050
Fire-clay brick	0.0050	1.81	2.05	1.91	24.1	0.069	24.84	1300
Checker brick	0.0039	1.42	2.65	1.91	27.8	0.0465	16.74	....
Bauxite brick	0.0033	1.19	3.12	1.92	38.4	0.212	76.39	1300
Silica brick	0.0020	0.71	2.75	1.58	42.58	0.0092	3.32	1050
Silica brick	0.0031	1.12	2.62	1.50	42.9	0.0536	192.9	1300
Magnesia brick	0.0065	2.35	3.39	2.00	41.0	0.0097	3.49	1300
Magnesia brick	0.0058	2.08	3.07	2.00	35.1	0.517	186.1	1050
Carborundum brick	0.0033	1.20	3.02	1.96	35.2	0.0053	1.90	1050
Carborundum brick	0.0145	5.22	2.83	1.96	30.6	0.0043	1.55	1300
Chromite (unburned)	0.0057	2.05	4.60	3.19	21.3	0.0568	20.45	....
Chromite brick (clay binder)	0.0034	1.23	3.38	2.49	26.4	0.0075	1.7	1300
Kieselguhr	0.0018	0.64	2.48	1.03	38.0	0.0957	34.45	....
Graphite brick	0.024	8.64	2.42	1.79	26.0	0.0	0.0	....
Porcelain	0.0046	1.66	......	......	......	......	......	1400
Building brick	0.0037	1.34	2.56	1.90	25.7	0.0015	0.53	1050
Light clay	0.0024	0.86	2.60	1.41	45.7	0.0164	5.90	....

In general, the conductivity increases with an increase in the original temperature and the temperature of using. Chromite, however, has a conductivity with practically no temperature coefficient.

[1] F. T. HAVARD, "Refractories and Furnaces."

Heat Conductivities of Refractories[1]

Specimen	Chem. analysis		Thickness	Apparent sp. gr.	True sp. gr.	Temp. range of measurement: Lower surface, deg.	Temp. range of measurement: Upper surface, deg.	Mean k	Remarks
Fire-clay	SiO_2	66.0	1½"	1.95	2.54	825	260	0.0029	Hard fired to
brick	Al_2O_3	31.0	....	....	....	970	300	0.0029	Seger cone
(Farnley).	Fe_2O_3	1.2	....	....	....	1080	330	0.0036	10—11 ap-
	CaO	0.3	....	....	....	1440	550	0.0040	proximately.
	MgO	0.9	1½"	....	....	1100	420	0.0033	Another
	Alk.	1.0	....	....	....	1350	510	0.0039	specimen.
Fire-clay	As above		1½"	1.90	2.67	1005	....	0.00165	Soft fired to
brick						1020	....	0.00120	Seger cone
(Farnley).									8—9 approximately.
Silicious	SiO_2	82.5	3"	1.82	2.53	1300	310	0.0025	With many
brick	Al_2O_3	16.1							silica grains.
(Farnley).	Fe_2O_3	1.2							
	CaO & MgO Tr.								
	Alk.	1.3							
Silica	SiO_2	95.3	2½"	1.75	2.32	1240	440	0.0039	
brick	Al_2O_3	2.0							
(Gregory).	FeO_3	1.1	2½"	1.74	2.32	995	295	0.0030	Another
	CaO	1.5	....	....	....	....	....	....	specimen.
						1210	370	0.0035	Both coarse
						1395	440	0.0042	grained.
Magnesia	SiO_2	5.0	2½"	2.40	3.51	380	270	0.0170	Finer grained
brick	Al_2O_3	0.4	....	....	....	560	325	0.0151	than the
(Mabor).	Fe_2O_3	1.6	....	....	....	600	400	0.0148	above.
	CaO	1.7	....	....	....	700	450	0.0132	
	MgO	92.1	....	....	....	750	470	0.0116	
						875	525	0.0110	
						1025	580	0.0101	
						1040	590	0.0098	
						1370	690	0.0091	

The chemical analysis and porosity data were not derived from measurements on the actual test brick but on similar specimens of the same make. They will correspond approximately with those of the test bricks.

[1] G. Dougill, H. J. Hodsman, and J. W. Cobb in *Journ. Soc. Chem. Ind.*, May 15, 1915.

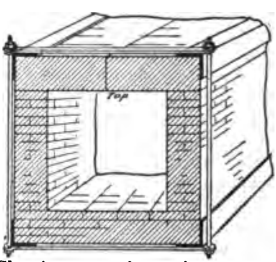
Heat Conductivities of Refractory Materials[1]

(See also Table on pp. 437 and 438.)

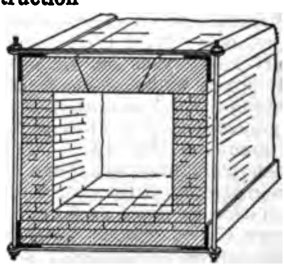
Material	Heat conductivity		
	Gallons cal. sec. p. sq. cm. p. cm. p. 1°C. diff.	Kg. cal. hr. p. sq. m. per m. p. 1°C. diff.	Relative per cent.
Graphite brick	0.025	9.0	100.0
Carborundum brick	0.0231	8.32	92.4
Magnesia brick	0.0071	2.54	28.4
Chromite brick	0.0057	2.05	22.8
Fire brick	0.0042	1.50	16.7
Checker brick	0.0039	1.42	15.8
Gas-retort brick	0.0038	1.36	15.2
Building brick	0.0035	1.26	14.0
Bauxite brick	0.0033	1.19	13.2
Glass pot	0.0027	0.96	12.4
Terra cotta	0.0023	0.84	9.3
Silica brick	0.0020	0.71	7.8
Kieselguhr brick	0.0018	0.64	7.1

The above are average conductivities only. The conductivity varies with the porosity, permeability, size, character and number of grains and pores in the brick, the temperature at which the brick was burned and the temperature at which it is used. In general the conductivity is greater the higher the temperature at which the brick is burned. Thus, a clay brick burned at 1050°C. has a conductivity of 1.32, while the same brick burned at 1300°C. has a conductivity of 1.81 (Havard). The conductivity also increases with increase of temperature of the experiment.

Arch Construction[2]



Showing way of covering over a flue on a small furnace without use of an arch. This is practical to spans as large as 30″ to 36″. This form of construction is particularly applicable where a flat covering is advantageous.



Showing manner of laying a "dutch arch," simple and cheap for spans up to 30″ to 40″ or even larger. This form of construction is particularly good where flat cover of larger size than the preceding is desired.

[1] Havard, "Furnaces and Refractories," p. 280.
[2] *Metallurgical and Chemical Engineering*, November, 1913.

SECTION IX

MECHANICAL ENGINEERING AND CONSTRUCTION

CAPACITY OF BELT CONVEYORS[1]

By R. W. Dull

Chief Engineer, Stephens-Adamson Mfg. Co.

The capacity of belt conveyors is a subject upon which various engineers differ materially in results they have published. We suspect that most of the matter published is purely theoretical and not based on actual performance.

There are several conditions which influence the capacity rating; the main one, and the one we will first discuss, is the manner of feeding the conveyor. If the conveyor is fed with a feeder, the maximum capacity is possible, but if the feed is intermittent, the capacity will, of course, be proportionately less. It is usually an advantage to put in a feeding device of some kind if the feed is irregular, as it is often possible to cut down the size of the conveyor, which difference in cost will more than pay for the cost of the feeding device, as well as cut down the size of the driving connections. Uniform loading of the belt also makes the operation of the conveyor less troublesome and usually is desirable in the different processes throughout a plant.

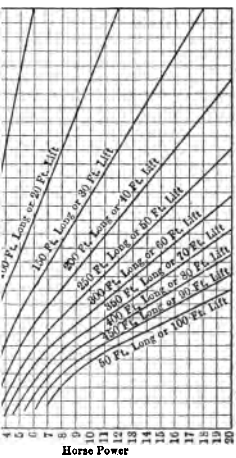
I have made a chart, which is based on good feeding conditions, as we must have some basis from which to start. This chart has curves for various kinds of material, based on the belt speed which I recommend that they should run for the particular kind of material. This speed is given in the curves. If good feeding conditions are not obtainable, allowance must be made on the chart. This is a condition which varies so much we cannot set down any rigid rule, but must leave it to the judgment of the user of the chart to make proper allowance. Variation as great as 50 per cent. is likely and certainly many where 75 per cent. of chart rating is advisable.

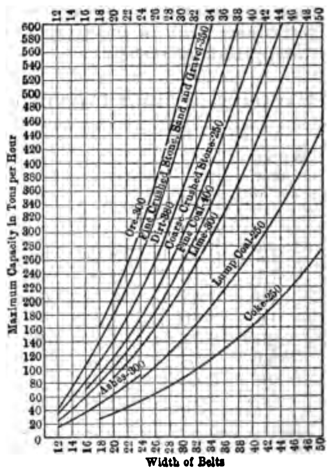
Materials undoubtedly will be handled which are not given in the chart, but as a similar substance can be selected, the chart can still be used.

The speed of the belts carrying various substances has been studied carefully to suit all conditions, as for instance, lump coal and coke, if carried too fast, will be broken up too much

[1] "The Chemical Engineer," Vol. X, No. 2.

the market; and again, very fine material, if carried too .ll make the mill too dusty.
: of the curves are stopped off at a certain size belt, as rge pieces, it is not advisable to use a conveyor any nar- regardless of what capacity is required.
:rial with large lumps, on an inclined conveyor, will be oll back some, so the capacity allowance should be liberal, e speed should be reduced slightly, if the conveyor is g material down an incline, as the motion of the belt will .e lumps rolling down. These lumps may possibly jump ;he trough of the belt.





eyors going up an incline and fed uniformly, can usually n angle whose tangent is greater than the coefficient of of material on the belt, because the material forms a op all the way up the incline. But if the feed is inter- , the material is apt to get started down the incline and tion of the belt will have no influence on the motion of :erial.
eyors should be fed so that the material is delivered in :ction of motion of the belt and with the same velocity belt is moving, if possible. The writer has devised a o accomplish this purpose and adjustment is possible various kinds of material and different belt speeds.)ut is also made with a bar screen bottom which lets the terial through onto the belt first which makes a cushion h the larger lumps fall and saves a great deal of wear on ,. It is not advisable to make small conveyors, such as

12-in. belts, too long, for the material will shift some and lose off before it reaches the end of the conveyor, and liberal allowance in capacity should be made if such a conveyor is installed.

The problem of belt conveyor capacity should be studied carefully and the allowances should be liberal. There have been very many disappointments in results caused by a too hasty decision or too great a desire to keep the first cost down.

Most firms are willing to help the purchaser, and it is usually a good plan to take up the matter of capacity with the manufacturer. It is not always easy for the manufacturer to find out all the conditions within so short an interval of time as he usually has at his disposal, and unless the manufacturer has had considerable experience with this type of conveyor, the purchaser may be led to install apparatus which gives him very disappointing results.

CAPACITY OF BELT CONVEYORS IN TONS OF COAL PER HOUR[1]

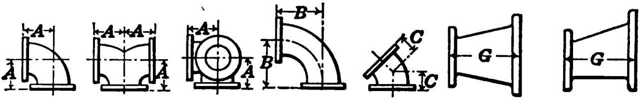
Width of belt, inches	Velocity of belt, feet per minute						
	300	350	400	450	500	550	600
12	27.0	31.5	36	40.5	45.0	49.5	54.0
14	36.7	42.8	49	55.2	61.3	67.4	73.6
16	48.0	56.0	64	72.0	80.0	88.0	96.0
18	60.7	70.8	81	91.2	101.0	111.0	135.0
20	75.0	87.5	100	112.5	125.0	137.5	150.0
24	108.0	126.0	144	162.0	180.0	198.0	216.0
30	168.7	197.0	225	253.0	281.0	307.0	338.0
36	243.0	283.0	324	365.0	405.0	446.0	386.0

For materials other than coal, the figures in the above table should be multiplied by the following coefficients.

Material	Coefficient	Material	Coefficient
Ashes damp	0.86	Earth	1.4
Cement	1.76	Sand	1.8
Clay	1.26	Crushed stone	2.0
Coke	0.60		

[1] KENT'S "Mechanical Engineers' Pocketbook."

THE NEW AMERICAN STANDARD FOR FLANGES AND FLANGED FITTINGS



STANDARD

Size	AA-Face to face, tees and crosses	A-Center to face, ells, tees, and crosses	B-Center to face, long radius ells	C-Center to face 45° ells	D-Face to face laterals	E-Center to face laterals	F-Center to face laterals	G-Face to face reducers	Diameter of flanges	Thickness of flanges	Minimum metal thickness of body
1	7	3 1/2	5	1 3/4	7 1/2	5 3/4	1 3/4		4	7/16	7/16
1 1/4	7 1/2	3 3/4	5 1/2	2	8	6 1/4	1 3/4		4 1/2	1/2	7/16
1 1/2	8	4	6	2 1/4	9	7	2		5	9/16	7/16
2	9	4 1/2	6 1/2	2 1/2	10 1/2	8	2 1/4		6	5/8	7/16
2 1/2	10	5	7	3	12	9 1/2	2 1/2		7	11/16	7/16
3	11	5 1/2	7 3/4	3	13	10	3	6	7 1/2	3/4	7/16
3 1/2	12	6	8 1/2	3 1/2	14 1/2	11 1/2	3	6 1/2	8 1/2	13/16	7/16
4	13	6 1/2	9	4	15	12	3	7	9	15/16	1/2
4 1/2	14	7	9 1/2	4	15 1/2	12 1/2	3	7 1/2	9 1/4	15/16	1/2
5	15	7 1/2	10 1/4	4 1/2	17	13 1/2	3 1/2	8	10	15/16	1/2
6	16	8	11 1/2	5	18	14 1/2	3 1/2	9	11	1	9/16
7	17	8 1/2	12 3/4	5 1/2	20 1/2	16 1/2	4	10	12 1/2	1 1/16	5/8
8	18	9	14	5 1/2	22	17 1/2	4 1/2	11	13 1/2	1 1/8	5/8
9	20	10	15 1/4	6	24	19 1/2	4 1/2	11 1/2	15	1 1/8	11/16
10	22	11	16 1/2	6 1/2	25 1/2	20 1/2	5	12	16	1 3/16	3/4
12	24	12	19	7 1/2	30	24 1/2	5 1/2	14	19	1 1/4	13/16
14	28	14	21 1/2	7 1/2	33	27	6	16	21	1 3/8	7/8
15	29	14 1/2	22 3/4	8	34 1/2	28 1/2	6	17	22 1/4	1 3/8	7/8
16	30	15	24	8	36 1/2	30	6 1/2	18	23 1/2	1 7/16	1
18	33	16 1/2	26 1/2	8 1/2	39	32	7	19	25	1 9/16	1 1/16
20	36	18	29	9 1/2	43	35	8	20	27 1/2	1 11/16	1 1/8
22	40	20	31 1/2	10	46	37 1/2	8 1/2	22	29 1/2	1 13/16	1 3/16
24	44	22	34	11	49 1/2	40 1/2	9	24	32	1 7/8	1 1/4
26	46	23	36 1/2	13	53	44	9	26	34 1/4	2	1 5/16
28	48	24	39	14	56	46 1/2	9 1/2	28	36 1/2	2 1/16	1 3/8
30	50	25	41 1/2	15	59	49	10	30	38 3/4	2 1/8	1 7/16
32	52	26	44	16				32	41 3/4	2 1/4	1 1/2
34	54	27	46 1/2	17				34	43 3/4	2 5/16	1 9/16
36	56	28	49	18				36	46	2 3/8	1 5/8
38	58	29	51 1/2	19				38	48 3/4	2 3/8	1 11/16
40	60	30	54	20				40	50 3/4	2 1/2	1 3/4
42	62	31	56 1/2	21				42	53	2 5/8	1 13/16
44	64	32	59	22				44	55 1/4	2 5/8	1 7/8
46	66	33	61 1/2	23				46	57 1/4	2 11/16	1 15/16
48	68	34	64	24				48	59 1/2	2 3/4	2
50	70	35	66 1/2	25				50	61 3/4	2 3/4	2 1/16
52	74	37	69	26				52	64	2 7/8	2 1/8
54	78	39	71 1/2	27				54	66 1/4	3	2 3/16
56	82	41	74	28				56	68 3/4	3	2 1/4
58	84	42	76 1/2	29				58	71	3 1/8	2 5/16

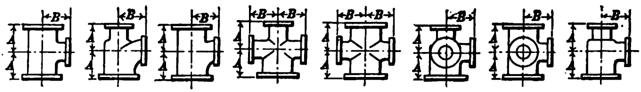
THE NEW AMERICAN STANDARD FOR FLANGES AND FLANGED FITTINGS. *Continued*

STANDARD

Size	AA-Face to face, tees and crosses	A-Center to face, ells, tees and crosses	B-Center to face, long radius ells	C-Center to face 45° ells	D-Face to face laterals	E-Center to face laterals	F-Center to face laterals	G-Face to face reducers	Diameter of flanges	Thickness of flanges	Minimum metal thickness of body
60	88	44	79	30				60	73	3⅛	2 7/16
62	90	45	81½	31				62	75¾	3¼	2½
64	94	47	84	32				64	78	3¼	2 9/16
66	96	48	86½	33				66	80	3⅜	2⅝
68	100	50	89	34				68	82¼	3⅜	2 11/16
70	102	51	91½	35				70	84½	3½	2¾
72	106	53	94	36				72	86½	3½	2 13/16
74	108	54	96½	37				74	88½	3⅝	2⅞
76	112	56	99	38				76	90¾	3⅝	2 15/16
78	116	58	101½	39				78	93	3¾	3
80	118	59	104	40				80	95¼	3¾	3 1/16
82	120	60	106½	41				82	97½	3⅞	3⅛
84	124	62	109	42				84	99¾	3⅞	3 3/16
86	126	63	111½	43				86	102	4	3¼
88	130	65	114	44				88	104¼	4	3 5/16
90	134	67	116½	45				90	106½	4⅛	3⅜
92	136	68	119	46				92	108¾	4⅛	3½
94	138	69	121½	47				94	111	4¼	3 9/16
96	142	71	124	48				96	113¼	4¼	3⅝
98	146	73	126½	49				98	115½	4⅜	3 11/16
100	148	74	129	50				100	117¾	4⅜	3¾

The dimensions given above are those adopted as a compromise by the committees responsible for the "U. S. 1912 Standard" and the competing "Manufacturers Standard."

The New American Standard for Flanges and Flanged Fittings. *Continued*



Standard

Size	*Size of outlet and smaller	AA-Face to face, run	A-Center to face, run	B-Center to face, outlet	Size	Size of outlet and smaller	AA-Face to face, run	A-Center to face, run	B-Center to face, outlet
1					42	28	46	23	30
1¼					44	28	46	23	31
1½					46	30	48	24	33
2					48	32	52	26	34
2½					50	32	52	26	35
3	All reducing fittings 1 in. to 9 in. inclusive have the same center to face dimensions as straight size fittings.				52	34	54	27	36
3½					54	36	58	29	37
4					56	36	58	29	39
4½					58	38	62	31	40
5					60	40	66	33	41
6					62	40	66	33	42
7					64	42	68	34	44
8					66	44	70	35	45
9					68	44	70	35	46
10	6	18	9	9½	70	46	74	37	47
12	8	20	10	11	72	48	80	40	48
14	9	22	11	13	74	48	80	40	49
15	9	23	11½	13½	76	50	84	42	50
16	10	24	12	14	78	52	86	43	52
18	12	26	13	15½	80	52	86	43	53
20	14	28	14	17	82	54	88	44	54
22	15	28	14	18	84	56	94	47	56
24	16	30	15	19	86	56	94	47	57
26	18	32	16	20	88	58	96	48	58
28	18	32	16	21	90	60	100	50	61
30	20	36	18	23	92	60	100	50	62
32	20	36	18	24	94	62	104	52	63
34	22	38	19	25	96	64	106	53	64
36	24	40	20	26	98	64	106	53	65
38	24	40	20	28	100	66	110	55	67
40	26	44	22	29	....	......	....	......	....

The dimensions given above are those adopted as a compromise by the committees responsible for the "U. S. 1912 Standard" and the competing "Manufacturers Standard."

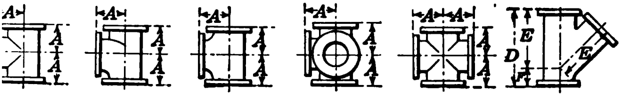
THE NEW AMERICAN STANDARD FOR FLANGES AND FLANGED FITTINGS.. *Continued*

EXTRA HEAVY

Size	* Size of outlet and smaller	AA-Face to face, run	A-Center to face, run	B-Center to face, outlet	Size	* Size of outlet and smaller	AA-Face to face, run	A-Center to face, run	B-Center to face, outlet
1	All reducing fittings 1 in. to 9 in. inclusive have the same center to face dimensions as straight size fittings.				16	10	25	12½	15½
1¼					18	12	28	14	17
1½					20	14	31	15½	18½
2					22	15	33	16½	20
2½					24	16	34	17	21½
3					26	18	38	19	23
3½					28	18	38	19	24
4					30	20	41	20½	25½
4½					32	20	41	20½	26½
5					34	22	44	22	28
6					36	24	47	23½	29½
7					38	24	47	23½	30½
8					40	26	50	25	31½
9					42	28	53	26½	33½
10	6	18	9	11	44	28	53	26½	34½
12	8	21	10½	12½	46	30	55	27½	35½
14	9	23	11½	14	48	32	58	29	37½
15	9	23	11½	15	......	....	....	....	......

The dimensions given above are those adopted as a compromise by the committees responsible for the "U. S. 1912 Standard" and the competing "Manufacturers Standard."

IE NEW AMERICAN STANDARD FOR FLANGES AND FLANGED FITTINGS. *Continued*

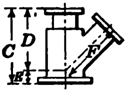


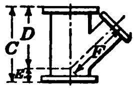
EXTRA HEAVY

Size	AA-Face to face, tees and crosses	A-Center to face, ells, tees and crosses	B-Center to face, long radius ells	C-Center to face 45° ells	D-Face to face, laterals	E-Center to face, laterals	F-Center to face, laterals	G-Face to face, reducers	Diameter of flanges	Thickness of flanges	Minimum metal thickness of body
1	8	4	5	2	8½	6½	2	......	4½	11/16	½
1¼	8½	4¼	5½	2½	9½	7¼	2¼	......	5	¾	½
1½	9	4½	6	2¾	11	8½	2½	......	6	13/16	½
2	10	5	6½	3	11½	9	2½	......	6½	⅞	½
2½	11	5½	7	3½	13	10½	2½	......	7½	1	9/16
3	12	6	7¾	3½	14	11	3	6	8¼	1⅛	9/16
3½	13	6½	8½	4	15½	12½	3	6½	9	1 3/16	9/16
4	14	7	9	4½	16½	13½	3	7	10	1¼	⅝
4½	15	7½	9½	4½	18	14½	3½	7½	10½	1 5/16	⅝
5	16	8	10¼	5	18½	15	3½	8	11	1⅜	11/16
6	17	8½	11½	5½	21½	17½	4	9	12½	1 7/16	¾
7	18	9	12¾	6	23½	19	4½	10	14	1½	13/16
8	20	10	14	6	25½	20½	5	11	15	1⅝	13/16
9	21	10½	15¼	6½	27½	22½	5	11½	16¼	1¾	⅞
0	23	11½	16½	7	29½	24	5½	12	17½	1⅞	15/16
2	26	13	19	8	33½	27½	6	14	20½	2	1
4	30	15	21½	8½	37½	31	6½	16	23	2⅛	1⅛
5	31	15½	22¾	9	39½	33	6½	17	24½	2 3/16	1 3/16
6	33	16½	24	9½	42	34½	7½	18	25½	2¼	1¼
8	36	18	26½	10	45½	37½	8	19	28	2⅜	1⅜
0	39	19½	29	10½	49	40½	8½	20	30½	2½	1½
2	41	20½	31½	11	53	43½	9½	22	33	2⅝	1 9/16
4	45	22½	34	12	57½	47½	10	24	36	2¾	1⅝
6	48	24	36½	13	......	......	......	26	38¼	2 13/16	1 13/16
8	52	26	39	14	......	......	......	28	40¾	2 15/16	1⅞
0	55	27½	41½	15	......	......	......	30	43	3	2
2	58	29	44	16	......	......	......	32	45¼	3⅛	2⅛
4	61	30½	46½	17	......	......	......	34	47½	3¼	2¼
6	65	32½	49	18	......	......	......	36	50	3⅜	2⅜
8	68	34	51½	19	......	......	......	38	52¼	3 7/16	2 7/16
0	71	35½	54	20	......	......	......	40	54½	3 9/16	2 9/16
2	74	37	56½	21	......	......	......	42	57	3 11/16	2 11/16
4	78	39	59	22	......	......	......	44	59¼	3¾	2 13/16
6	81	40½	61½	23	......	......	......	46	61½	3⅞	2⅞
8	84	42	64	24	......	......	......	48	65	4	3

The dimensions given above are those adopted as a compromise by the mmittees responsible for the "U. S. 1912 Standard" and the competing Manufacturers Standard."

The New American Standard for Flanges and Flanged Fittings. *Continued*





Standard						Extra Heavy					
Size	* Size of branch and smaller	C-Face to face, run	D-Center to face, run	E-Center to face, run	F-Center to face, branch	Size	* Size of branch and smaller	C-Face to face, run	D-Center to face, run	E-Center to face, run	F-Center to face, branch
1 1¼ 1½ 2 2½	All reducing fittings 1-3½ in. inclusive have same center to face dimensions as straight size fittings.					1 1¼ 1½ 2 2½	All reducing fittings 1-3½ in. inclusive have same center to face dimensions as straight size fittings.				
3						3					
3½						3½					
4	2½	13	11	2	11	4	2½	14	12	2	13
4½	2½	13	11	2	11	4½	2½	15	12½	2½	13½
5	3	14	12	2	12	5	3	16	13½	2½	14½
6	3	15	13½	1½	13½	6	3	17	14½	2½	15½
7	3½	16	14½	1½	15	7	3½	18	15½	2½	16½
8	4	16	14½	1½	15½	8	4	20	17½	2½	18½
9	4½	17	15½	1½	16½	9	4½	21	18½	2½	19½
10	5	18	17	1	18	10	5	23	20½	2½	21½
12	6	20	19	1	20½	12	6	26	23½	2½	24½
14	7	22	21	1	23	14	7	29	26½	2½	27½
15	7	23	22	1	24	15	7	30	27½	2½	28½
16	8	24	23	1	25½	16	8	32	29	3	30½
18	9	26	25	1	27½	18	9	34	31	3	32½
20	10	28	27	1	29½	20	10	37	34	3	36
22	10	29	28½	½	31½	22	10	40	37	3	39
24	12	32	31½	½	34½	24	12	44	41	3	43
26	12	35	35	0	38	......	......	......	......	......	......
28	14	37	37	0	40	......	......	......	......	......	......
30	15	39	39	0	42						

The dimensions given above are those adopted as a compromise by the committees responsible for the "U. S. 1912 Standard" and the competing "Manufacturers Standard."

Safe Loads for Ropes and Chains

(In pounds)

Prepared by National Founders' Association

·ion: When handling molten metal, wire ropes and chains should be cent. stronger than indicated in table.

:.—The safe loads in table · each *single* rope or chain. used double or in other les the loads may be in- l proportionately.			When used straight	When used at 60° angle	When used at 45° angle	When used at 80° angle
		Dia.				
		3/8″	1,500	1,275	1,050	750
		1/2	2,400	2,050	1,700	1,200
Steel Wire Rope		5/8	4,000	3,400	2,800	2,000
nds of 19 or 37		3/4	6,000	5,100	4,200	3,000
If crucible steel		7/8	8,000	6,800	5,600	4,000
, used reduce loads		1	10,000	8,500	7,000	5,000
th.		1 1/8	13,000	11,000	9,000	6,500
		1 1/4	16,000	13,500	11,000	8,000
		1 3/8	19,000	16,000	13,000	9,500
		1 1/2	22,000	19,000	16,000	11,000
		Dia. of iron				
		1/4″	600	500	425	350
		3/8	1,200	1,025	850	600
'rane Chain		1/2	2,400	2,050	1,700	1,200
;rade of wrought		5/8	4,000	3,400	2,800	2,000
and-made, tested,		3/4	5,500	4,700	3,900	2,750
nk chain.)		7/8	7,500	6,400	5,200	3,700
		1	9,500	8,000	6,600	4,700
		1 1/8	12,000	10,200	8,400	6,000
		1 1/4	15,000	12,750	10,500	7,500
		1 3/8	22,000	19,000	16,000	11,000
	Dia.	Cir.				
	3/8″	1 ″	120	100	85	60
	1/2	1 1/2	250	210	175	125
	5/8	2	360	300	250	180
	3/4	2 1/4	520	440	360	260
	7/8	2 3/4	620	520	420	300
ila Rope		3	750	625	525	375
long fiber	1 1/8	3 1/2	1,000	850	700	500
:.)	1 1/4	3 3/4	1,200	1,025	850	600
	1 1/2	4 1/2	1,600	1,350	1,100	800
	1 3/4	5 1/2	2,100	1,800	1,500	1,050
	1	6	2,800	2,400	2,000	1,400
	2 1/2	7 1/2	4,000	3,400	2,800	2,000
	2	9	6,000	5,100	4,200	3,000
	3					

ANNEALING CHAINS[1]

For many years The Travelers Insurance Company has recommended the periodical annealing of chains that are subject to severe usage, such as those that are used on cranes, dredges, and chain hoists, and for slings and for other heavy work, although many prominent authorities firmly believe that such treatment is inadvisable. A recent canvass of a considerable number of chain manufacturers shows that those in favor of the annealing process outnumber those opposed to it by about five to one, although the advocates of annealing are not in harmony as to the methods employed, the frequency of annealing, the temperature to which the chains are to be subjected, or the length of time required to insure good results.

All chain manufacturers, and practically all chain users, are aware of the fact that rough usage, shocks, and twists tend to weaken chains. A change gradually occurs in the molecular composition of the material, and the strength of the chain becomes seriously impaired. This is known as "fatigue" of the metal. There may be no visible evidence of this deterioration, although a careful microscopic examination would doubtless disclose a multitude of small cracks; but a person accustomed to the use of chains knows that deterioration is going on, and that eventually the chains will fail. When a chain has been in service for a sufficient length of time to make it unsafe for use at the load for which it was originally designed, it would be desirable to discard it, or at least to use it only for lighter loads; but such a course is not always practicable, nor, according to the views of the advocates of annealing, is it necessary, because the process of annealing counteracts the effects of fatigue and restores the chain to nearly its original strength.

As to the proper method of doing the work, a pyrometer-controlled muffle furnace is the best thing possible. Open fires are bad because it is difficult to guess the temperature of the chain, and impossible to hold the temperature steady. The Committee on Heat Treatment, of the American Society for Testing Materials, recommends the following annealing temperatures.

Carbon content	Annealing temperature
Less than 0.12 per cent	875–925°C. (1607–1697°F.)
0.12–0.25 per cent	840–870°C. (1544–1598°F.)
0.30–0.49 per cent	815–840°C. (1499–1544°F.)
0.50–1.00 per cent	790–815°C. (1454–1499°F.)

If an open fire must be used, heat to a cherry red in a wood fire, then let the fire die out, and allow the chain to cool in the ashes.

Various methods for testing chains are employed by persons who have no faith in the annealing process. The method advocated by the Yale & Towne Manufacturing Co. and by the Brown & Sharpe Manufacturing Co. is to make use of a gage 3

[1] From the "Travelers Standard," p. 122, 1915.

long. Every new chain is marked with a prick-punch at ervals of 3 ft., and at each subsequent inspection of the chain : prick-punch marks are compared with the gage. If it is ınd that a section of the chain between two of the marks has etched by an amount equal to one-third of the length of a k, the chain is considered unsafe and is condemned, or is used some place where it will be subjected only to light loads. It sometimes found that only a single section of the chain must discarded. The experience of users of chains who have opted this method for testing them has been satisfactory, in : main, and accidents from breaking chains have been terially reduced by it. Manifestly, however, it would not ply without modification to chains having unusually large ks.

Many authorities on chains, even though admitting that ıg chains should be annealed, insist that block chains that ss over sheaves should not be treated in this way. The dan- from molecular changes caused by overloading the chains y be greatly diminished by proper annealing, but when dis- tion of the links occurs in block chains the chains no longer the sheaves, and excessive wear results, often accompanied by ere and badly distributed stresses. No amount of annealing ı restore the links to their original lengths, and the only prac- al remedy, when such distortion has occurred, is to substitute w chains.

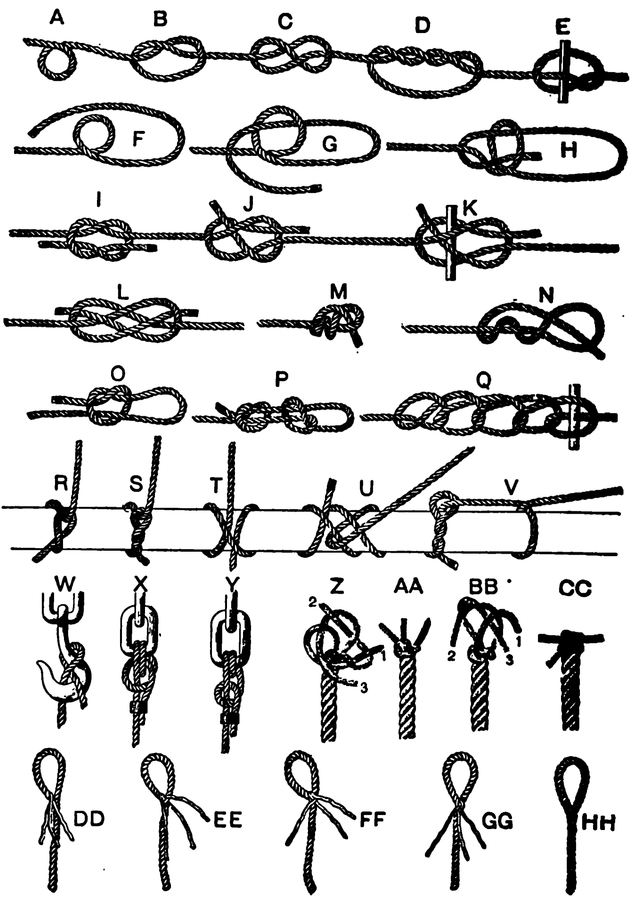
BER ROPE KNOTS AND HITCHES—AND HOW TO MAKE THEM

The principle of a knot is that no 2 parts which would move the same direction if the rope were to slip, should lie alongside and touching each other. This principle is clearly shown in : square knot (I).

A great number of knots have been devised, of which a few of : most useful are herewith illustrated by courtesy of C. W. ınt Company, of New York. In the engravings they are own open, or before being drawn taut, in order to show the sition of the parts. The names usually given to them are:

A. Bight of a rope.
B. Simple or overhand knot.
C. Figure 8 knot.
D. Double knot.
E. Boat knot.
F. Bowline, first step.
G. Bowline, second step.
H. Bowline, completed.
I. Square or reef knot.
J. Sheet bend or weaver's knot.
K. Sheet bend with a toggle.
L. Carrick bend.
M. "Stevedore" knot completed.
N. "Stevedore" knot commenced.

O. Slip knot.
P. Flemish loop.
Q. Chain knot with toggle.
R. Half-hitch.
S. Timber-hitch.
T. Clove-hitch.
U. Rolling-hitch.
V. Timber-hitch and half-hitch.
W. Blackwall-hitch.



X. Fisherman's bend.
Y. Round turn and half-hitch.
Z. Wall knot commenced.
AA. Wall knot completed.
BB. Wall knot crown commenced.
CC. Wall knot crown completed.
DD to HH. Eye splice commenced and completed.

The bowline (G) is one of the most useful knots; it will not slip, and after being strained is easily untied. It should be tied with facility by everyone who handles rope. Commence by making a bight in the rope, then put the end through the bight and under the standing part, as shown in the engraving, then pass the end again through the bight, and haul tight.

The square or reef knot (1) must not be mistaken for the "granny" knot that slips under a strain. Knots (H, K and M) are easily untied after being under strain. The knot (M) is useful when the rope passes through an eye and is held by the knot, as it will not slip, and is easily untied after being strained.

The wall knot looks complicated, but is easily made by proceeding as follows:

Form a bight with strand 1, and pass the strand 2 around the end of it, and the strand 3 around the end of 2, and then through the bight of 1, as shown in engraving Z. Haul the ends taut, when the appearance is as shown in the engraving AA. The end of the strand 1 is now laid over the center of the knot, strand 2 laid over 1, and 3 over 2, when the end of 3 is passed through the bight of 1, as shown in the engraving BB. Haul all the strands taut, as shown in the engraving CC.

The "stevedore" knot (M), (N) is used to hold the end of a rope from passing through a hole. When the rope is strained the knot draws up tight, but it can be easily untied when the strain is removed.

If a knot or hitch of any kind is tied in a rope, its failure under stress is sure to occur at that place. Each fiber in the straight part of the rope takes proper share of the load, but in all knots the rope is cramped or has a short bend, which throws an overload on those fibers that are on the outside of the bend and one fiber after another breaks until the rope is torn apart. The shorter the bend in the standing rope, the weaker is the knot.

FORMULAS FOR PUMPS AND PIPING[1]

To find	Given	Formulas
1. Pressure in lb. per sq. in. = P.	Head in ft. = H	$P = H \times 0.433$.
2. Head in ft. = H.	Pressure in lb. per sq. in. = P.	$H = P \times 2.312$.
3. Horsepower required to raise water (theoretical).	Gal. per min. = G. Head in ft. = H.	$\text{H.p.} = \frac{G \times H}{3{,}300}$
4. Volume of water discharged by pipe (neglecting bends and friction).	Internal dia. of pipe in in. = D. Head in ft. = H. Length of pipe in yards = L.	Gal. per min.: $= 28\sqrt{\frac{D^5 \times H}{L}}$
5. Theoretical capacity of single-acting pump.	Area of ram in in. = A. Stroke in in. = S. No. of strokes per min. = N.	Gal. per min.: $= \frac{A \times S \times N \times 6.25}{1728}$.
6. Dia. in in. of single-acting pump to deliver given number of gals. per stroke.	Gal. per stroke = G. Stroke in ft. = S.	Dia. of pump $= \sqrt{\frac{31G}{S}}$ (allowing 5 per cent. waste).
7. Feet head lost by friction in pipes = F.	Gal. per min. = G. Length of pipe in yards = L. Internal dia. of pipe in in. = D.	$F = \frac{G^2 \times L}{(3D)^5}$.
8. Approx. weight of water in vertical pipes in lb. = W.	Internal dia. of pipe in in. = D. Length of pipe in yards = L.	$W = D^2 \times L$.
9. Thickness of cast-iron pipes in in. = T.	Internal dia. of pipe in in. = D. Pressure in lb. per sq. in. = P.	$T = \frac{D \times P}{4{,}000} + 0.3$.
10. Delivery per stroke of single-acting pump.	Dia. of plunger in in. = D. Stroke in ft. = S.	Gal. delivered per stroke $= \frac{D^2 \times S}{31}$ (allowing 5 per cent. waste).
11. Speed of water through pipes in ft. per sec.	Area in pipe in in. = A. Discharge in cu. ft. per min. = F.P.M.	Velocity ft. per sec. $= \frac{\text{F.P.M.} \times 2.4}{A}$
12. Velocity in ft. per sec. due to head = V.	H = head. g = 32.2.	$V = \sqrt{2gH}$
13. Head from velocity.	....	$H = \frac{V^2}{2g}$
14. Imperial gallons..	Cubic feet = C	Imperial gallons = $C \times 6.25$.
15. Cubic feet.......	Gallons (Imperial) = G.	Cubic feet = $G \times 0.16$.

[1] G. S. BURROWS, in *American Machinist*, Aug. 20, 1914.

Water Pressure at Various Heads

Feet head	Pounds per sq. in.	Feet head	Pounds per sq. in.	Feet head	Pounds per sq. in.	Feet head	Pounds per sq. in.	Feet head	Pounds per sq. in.
.....	....	130	56.31	195	84.47	260	112.62	350	151.61
.....	....	135	58.48	200	86.63	265	114.79	360	155.94
.....	....	140	60.64	205	88.80	270	116.96	370	160.27
.....	....	145	62.81	210	90.96	275	119.12	380	164.61
.....	....	150	64.97	215	93.14	280	121.29	390	168.94
.....	....	155	67.14	220	95.30	285	123.45	400	173.27
								450	194.92
		160	69.31	225	97.49	290	125.62	500	216.58
								550	238.24
100	43.31	165	71.47	230	99.63	295	127.78	600	259.90
								650	281.56
105	45.48	170	73.64	235	101.79	300	129.95	700	303.22
								750	324.88
110	47.64	175	75.80	240	103.96	310	134.28	800	346.54
								850	368.20
115	49.81	180	77.97	245	106.13	320	138.62	900	389.86
								950	411.52
120	51.98	185	80.14	250	108.29	330	142.95	1000	433.18
125	54.15	190	82.30	255	110.46	340	147.28		

For heads under 100 ft., take the figure corresponding to 10 (or 100) times the given head and move the decimal point one (or two) places to the left.

Flow of Gas in Pipes[1]

If d = Diameter of pipe in inches.
Q = Quantity of gas in cu. ft. per hour.
l = Length of pipe in yards.
h = Pressure in inches of water.
s = Specific gravity of gas, air being 1,

then

$$d = \sqrt[5]{\frac{Q^2 sl}{(1350)^2 h}}$$

$$h = \frac{Q^2 sl}{(1350)^2 d^5}$$

$$Q = 1350 d^2 \sqrt{\frac{dh}{sl}} = 1350 \sqrt{\frac{d^5 h}{sl}}$$

or Molesworth gives $Q = 1000\sqrt{\dfrac{d^5 h}{sl}}$

while J. P. Gill gives $Q = 1291\sqrt{\dfrac{d^5 h}{s(l+d)}}$

[1] Kent, "Mechanical Engineers' Pocket Book."

TABLE FOR CONVERTING "COMPRESSED AIR" INTO "FREE AIR"[1]

Altitude	Barometer	Atmospheric pressure	Gage pressure													
			45	50	55	60	65	70	75	80	85	90	95	100	105	110
0	30.00	14.7	4.06	4.40	4.74	5.08	5.42	5.76	6.10	6.44	6.78	7.12	7.46	7.80	8.14	8.48
500	29.45	14.45	4.11	4.46	4.80	5.15	5.50	5.83	6.19	6.53	6.88	7.23	7.57	7.92	8.26	8.61
1,000	28.90	14.12	4.18	4.54	4.89	5.24	5.60	5.95	6.31	6.66	7.02	7.37	7.72	8.08	8.43	8.79
1,500	28.35	13.92	4.23	4.59	4.95	5.31	5.67	6.03	6.39	6.75	7.10	7.46	7.82	8.18	8.54	8.90
2,000	27.78	13.61	4.30	4.67	5.05	5.41	5.77	6.14	6.51	6.88	7.24	7.61	7.98	8.34	8.71	9.08
3,000	26.75	13.10	4.43	4.81	5.20	5.58	5.96	6.34	6.72	7.10	7.49	7.87	8.25	8.63	9.01	9.40
4,000	25.75	12.61	4.57	4.96	5.36	5.76	6.15	6.55	6.95	7.34	7.74	8.14	8.53	8.93	9.32	9.72
5,000	24.78	12.15	4.70	5.11	5.52	5.94	6.35	6.76	7.17	7.58	7.99	8.40	8.82	9.22	9.64	10.05
6,000	23.86	11.75	4.83	5.24	5.68	6.16	6.53	6.96	7.38	7.81	8.23	8.66	9.08	9.51	9.93	10.36
7,000	22.97	11.27	4.99	5.43	5.88	6.32	6.77	7.21	7.65	8.10	8.54	8.98	9.43	9.87	10.32	10.76
8,000	22.10	10.85	5.14	5.61	6.07	6.53	6.99	7.45	7.91	8.37	8.83	9.29	9.75	10.21	10.68	11.14
9,000	21.30	10.45	5.31	5.78	6.26	6.74	7.22	7.70	8.19	8.67	9.13	9.61	10.09	10.57	11.05	11.52
10,000	20.60	10.10	5.45	5.95	6.44	6.94	7.43	7.93	8.42	8.92	9.41	9.91	10.40	10.90	11.40	11.88

Example: Given 348 cu. ft. of air compressed to 95 lb. pressure at 4000 ft. altitude. Opposite 4000 and below 95 appears the figure 8.53. 8.53 × 348 = 2968.44 = volume in "free air."

[1] Sullivan Machinery Co.'s Catalog.

HORSEPOWER (THEORETICAL) REQUIRED TO COMPRESS 100 CU. FT. FREE AIR TO VARIOUS PRESSURES[1]

Gage pressure	Single-stage	Two-stage	Saving of two-stage over single-stage compression	
			Horsepower	Per cent.
5	1.97	....	....	....
10	3.61	....	....	....
15	5.02	....	....	....
20	6.28	....	....	....
25	7.44	....	....	....
30	8.45	....	....	....
35	9.41	....	....	....
40	10.30	....	....	....
45	11.13	....	....	....
50	11.92	10.65	1.28	10.70
55	12.67	11.25	1.42	11.22
60	13.37	11.81	1.57	11.72
65	14.05	12.34	1.71	12.18
70	14.70	12.84	1.85	12.61
75	15.32	13.32	2.00	13.04
80	15.91	13.77	2.13	13.40
85	16.48	14.21	2.27	13.77
90	17.04	14.63	2.41	14.12
95	17.57	15.03	2.54	14.45
100	18.09	15.42	2.67	14.77
110	19.08	16.15	2.93	15.36
120	20.01	16.83	3.18	15.90
130	20.90	17.46	3.43	16.42
140	21.74	18.07	3.67	16.89
150	22.55	18.64	3.91	17.33
160	23.32	19.26	4.06	17.40
170	24.06	19.78	4.29	17.80
180	24.77	20.27	4.51	18.18
190	25.46	20.74	4.70	18.46
200	26.12	21.19	4.93	18.88
210	....	21.54	....	....
220	....	21.96	....	....
230	....	22.37	....	....
240	....	22.76	....	....
250	....	23.03	....	....
260	....	23.28	....	....
270	....	23.84	....	....
280	....	24.19	....	....
290	....	24.53	....	....
300	....	24.85	....	....
350	....	26.35	....	....
400	....	27.65	....	....
450	....	28.85	....	....
500	....	29.97	....	....

To secure the actual horsepower required to compress a given volume of air to any desired pressure, 10 to 15 per cent. should be added to the figures shown above, depending upon the size and type of the compressor, to allow for mechanical losses.

[1] Sullivan Machinery Co.'s Catalog.

Approximate Cubic Feet of Free Air and Working Pressure Required to Raise 1 Gal. of Water by Air Lift[1]

$$V = \frac{L}{\text{Log}\ \frac{H + 34}{34} \times 292.5}$$

H = Submergence in feet.
L = Lift in feet.

Ft. lb. working power = submergence × 0.4465 + 7 lb.
V = Volume of free air per gallon in cubic feet.

Ratio of Submergence to Lift

Lift in feet	25 per cent. ⅓–1			33 per cent. ½–1			43 per cent. ¾–1			50 per cent. 1–1			
	Free air, cu. ft.	Working pressure	Horse-power	F. A. C. F.	W. P.	H. P.	F. A. C. F.	W. P.	H. P.	F. A. C. F.	W. P.	H. P.	
20	....	....	....	....	....	....	....	....	....	0.34	16	.018	1-Stage
30	....	....	....	....	....	....	....	....	....	0.38	20	.024	
40	....	....	....	....	....	....	....	....	....	0.41	25	.031	
50	....	....	....	....	....	....	....	....	....	0.44	29	.036	
60	....	....	....	....	....	....	....	....	....	0.47	34	.043	
80	....	....	....	....	....	....	....	....	....	0.52	43	.056	
100	....	....	....	....	....	....	0.68	40	.070	0.58	52	.071	
120	....	....	....	....	....	....	0.73	47	.084	0.63	61	.075	2-Stage
140	....	....	....	....	....	....	0.79	54	.099	0.68	70	.087	
160	....	....	....	....	....	....	0.84	61	.100	0.73	78	.099	
180	....	....	....	....	....	....	0.88	67	.110	0.77	88	.111	
200	1.44	37	.141	1.15	52	.141	0.93	74	.123	0.82	96	.124	
250	1.57	44	.172	1.27	63	.154	1.05	91	.154	0.92	119	.154	
300	1.69	52	.207	1.40	74	.186	1.20	107	.191	1.03	141	.187	
350	1.82	59	.241	1.50	85	.213	1.31	124	.224	1.16	163	.225	
400	1.96	66	.244	1.63	96	.246	1.38	141	.250	1.23	186	.253	
450	2.08	74	.276	1.74	107	.277	1.48	157	.282	1.33	208	.267	3-Stage
500	2.19	82	.306	1.86	119	.312	1.56	174	.312	1.43	230	.299	
550	2.30	88	.333	1.96	130	.342	1.68	191	.349	1.52	253	.329	
600	2.41	96	.364	2.05	141	.372	1.78	208	.358	1.61	275	.360	
650	2.52	104	.396	2.18	152	.409	1.87	226	.388	1.74	297	.400	
700	2.64	111	.428	2.27	163	.441	1.96	240	.416	1.81	320	.427	
750	2.76	119	.463	2.37	174	.473	2.06	258	.450	1.88	342	.454	
800	2.88	126	.496	2.47	186	.508	2.15	275	.480	1.97	364	.486	
850	2.97	133	.524	2.57	197	.542	2.24	292	.512	2.06	387	.519	
900	3.07	141	.557	2.67	208	.537	2.33	308	.542	2.14	409	.550	
950	3.18	149	.591	2.76	219	.566	2.40	325	.567	2.22	431	.579	
1000	3.28	156	.622	2.86	230	.598	2.77	342	.609	2.31	453	.614	

[1] Sullivan Machinery Co.'s Catalog.

Approximate Cubic Feet of Free Air and Working Pressure Required to Raise 1 Gal. of Water by Air Lift—*Continued.*

Lift in feet	55 per cent. 1¼-1			60 per cent. 1½-1			66 per cent. 2-1			70 per cent. 2⅓-1			
	F. A. C. F.	W. P.	H. P.	F. A. C. F.	W. P.	H. P.	F. A. C. F.	W. P.	H. P.	F. A. C. F.	W. P.	H. P.	
20	0.29	18	.017	0.25	20	.016	0.20	25	.015	0.17	29	.014	1-Stage
30	0.32	24	.023	0.28	27	.022	0.23	34	.021	0.20	40	.021	
40	0.35	29	.029	0.31	34	.029	0.26	43	.028	0.23	52	.028	
50	0.38	35	.036	0.34	40	.035	0.29	52	.035	0.26	63	.032	2-Stage
60	0.41	40	.042	0.37	47	.042	0.32	61	.038	0.28	74	.037	
70	0.46	52	.056	0.42	61	.050	0.36	78	.049	0.33	96	.050	
100	0.51	63	.062	0.47	74	.062	0.41	96	.062	0.37	119	.062	
120	0.56	74	.074	0.52	87	.075	0.46	114	.076	0.42	141	.076	
140	0.61	85	.087	0.56	101	.087	0.50	132	.088	0.46	163	.089	
160	0.66	96	.100	0.60	114	.099	0.54	150	.101	0.50	186	.103	
180	0.70	108	.112	0.65	127	.112	0.58	168	.114	0.54	208	.109	3-Stage
200	6.74	119	.124	0.69	141	.125	0.62	186	.127	0.58	230	.121	
250	0.86	147	.159	0.79	174	.158	0.72	230	.151	0.67	286	.152	
300	0.96	174	.192	0.89	208	.179	0.81	275	.181	0.76	342	.184	
350	1.05	202	.209	0.98	241	.209	0.89	320	.211	0.84	398	.214	
400	1.14	230	.238	1.08	275	.241	0.98	364	.242	0.93	453	.247	
450	1.23	258	.269	1.17	308	.272	1.07	409	.275	1.02	509	.282	
500	1.32	286	.299	1.26	342	.304	1.15	453	.306	1.09	565	.308	
550	1.42	328	.338	1.34	375	.334	1.25	498	.343	....	...	....	
600	1.51	342	.365	1.42	409	.365	1.31	543	.369	....	...	....	
650	1.61	370	.400	1.52	442	.401	1.39	587	.402	....	...	....	
700	1.68	398	.428	1.60	476	.432	1.47	632	.435	....	...	....	
750	1.78	425	.463	1.66	509	.458	1.55	677	.468	....	...	....	
800	1.86	453	.494	1.75	543	.493	1.65	721	.507	....	...	....	
850	1.93	481	.523	1.82	576	.523	1.70	766	.533	....	...	....	
900	2.00	509	.552	1.86	610	.544	1.77	811	.564	....	...	....	
950	2.08	536	.584	1.99	643	.591	1.85	855	.599	....	...	....	
1000	2.17	565	.618	2.06	677	.622	1.93	900	.634	....	...	....	

Volumetric and Horsepower Coefficients for Two-stage Air Compression[1]

Altitude in feet	Barom. press., in lb. per sq. in.	Terminal gage pressure, pounds per square inch. 70 H.p. coeff.	70 Volum. coeff.	80 H.p. coeff.	80 Volum. coeff.	90 H.p. coeff.	90 Volum. coeff.	100 H.p. coeff.	100 Volum. coeff.	120 H.p. coeff.	120 Volum. coeff.	140 H.p. coeff.	140 Volum. coeff.	150 H.p. coeff.	150 Volum. coeff.
Sea level	14.72	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1,000	14.17	0.98	0.97	0.98	0.97	0.98	0.97	0.98	0.97	0.98	0.97	0.98	0.97	0.98	0.97
2,000	13.64	0.97	0.94	0.96	0.94	0.96	0.94	0.96	0.94	0.96	0.93	0.96	0.93	0.96	0.93
3,000	13.13	0.95	0.91	0.95	0.91	0.94	0.91	0.94	0.91	0.94	0.90	0.94	0.90	0.94	0.90
4,000	12.64	0.93	0.88	0.93	0.88	0.93	0.88	0.92	0.88	0.92	0.87	0.92	0.87	0.92	0.87
5,000	12.17	0.91	0.85	0.91	0.85	0.91	0.85	0.91	0.85	0.90	0.84	0.90	0.84	0.90	0.84
6,000	11.71	0.90	0.82	0.89	0.82	0.89	0.82	0.89	0.82	0.88	0.82	0.88	0.81	0.88	0.81
7,000	11.27	0.88	0.80	0.88	0.79	0.87	0.79	0.87	0.79	0.86	0.79	0.86	0.78	0.86	0.78
8,000	10.85	0.86	0.77	0.86	0.77	0.85	0.77	0.85	0.76	0.85	0.76	0.84	0.76	0.84	0.76
9,000	10.45	0.85	0.75	0.84	0.74	0.84	0.74	0.83	0.74	0.83	0.73	0.82	0.73	0.82	0.73
10,000	10.06	0.83	0.72	0.83	0.72	0.82	0.72	0.82	0.71	0.81	0.71	0.81	0.71	0.80	0.70
11,000	9.69	0.82	0.70	0.81	0.70	0.80	0.69	0.80	0.69	0.79	0.68	0.79	0.68	0.79	0.68
12,000	9.33	0.80	0.68	0.79	0.67	0.79	0.67	0.78	0.67	0.78	0.66	0.77	0.66	9.77	0.66
13,000	8.98	0.78	0.65	0.78	0.65	0.77	0.65	0.77	0.64	0.76	0.64	0.75	0.63	0.75	0.63
14,000	8.64	0.77	0.63	0.77	0.63	0.76	0.62	0.75	0.62	0.74	0.62	0.74	0.61	0.74	0.61
15,000	8.32	0.75	0.61	0.74	0.61	0.74	0.60	0.74	0.60	0.73	0.59	0.72	0.59	0.72	0.59

[1] Sullivan Machinery Co.'s Catalog.

HORSEPOWER PER 100 CUBIC FEET FREE AIR PER MINUTE, TWO-STAGE COMPRESSION; THEORETICAL HORSEPOWER IN AIR CYLINDERS[1]

(Allow for Friction and other Losses)

Altitude in feet	Barom. press., lb. per sq. in.	Terminal gage pressure											
		70	75	80	85	90	95	100	110	120	130	140	150
Sea level	14.72	12.84	13.32	13.78	14.21	14.63	15.03	15.42	16.15	16.83	17.47	18.07	18.64
1,000	14.17	12.62	13.08	13.52	13.95	14.35	14.74	15.12	15.83	16.49	17.11	17.69	18.25
2,000	13.64	12.39	12.84	13.27	13.68	14.08	14.46	14.82	15.51	16.15	16.76	17.33	17.86
3,000	13.13	12.17	12.61	13.03	13.43	13.81	14.18	14.53	15.20	15.83	16.41	16.96	17.48
4,000	12.64	11.94	12.37	12.78	13.17	13.54	13.90	14.25	14.90	15.50	16.07	16.61	17.11
5,000	12.17	11.72	12.14	12.54	12.92	13.28	13.63	13.96	14.60	15.19	15.74	16.25	16.75
6,000	11.71	11.51	11.91	12.30	12.66	13.02	13.35	13.68	14.29	14.86	15.40	15.90	16.38
7,000	11.27	11.29	11.68	12.06	12.41	12.76	13.09	13.40	14.00	14.55	15.07	15.56	16.02
8,000	10.85	11.07	11.46	11.83	12.17	12.50	12.82	13.13	13.71	14.25	14.75	15.22	15.67
9,000	10.45	10.87	11.24	11.59	11.93	12.26	12.57	12.86	13.42	13.95	14.44	14.90	15.33
10,000	10.06	10.66	11.02	11.37	11.69	12.01	12.31	12.60	13.14	13.65	14.12	14.57	14.99
11,000	9.69	10.46	10.81	11.14	11.46	11.76	12.06	12.34	12.87	13.36	13.82	14.26	14.67
12,000	9.33	10.25	10.59	10.92	11.22	11.52	11.81	12.08	12.60	13.07	13.52	13.94	14.34
13,000	8.98	10.05	10.38	10.70	11.00	11.28	11.56	11.83	12.32	12.79	13.23	13.63	14.02
14,000	8.64	9.85	10.17	10.48	10.77	11.05	11.31	11.57	12.06	12.51	12.92	13.32	13.70
15,000	8.32	9.65	9.97	10.26	10.55	10.82	11.08	11.33	11.79	12.23	12.64	13.03	13.39

[1] Sullivan Machinery Co.'s Catalog.

Air Lifts—Ratio of Lift to Submergence[1]

Lift	Submergence
Up to 50 ft.	70–66 per cent.
50–100 ft.	66–55 per cent.
100–200 ft.	55–50 per cent.
200–300 ft.	50–43 per cent.
300–400 ft.	43–40 per cent.
400–500 ft.	40–33 per cent.

METALLURGICAL CONSTRUCTION

Allowable Unit Strains For Metallurgical Works[2]

Substructure

Foundations.—Pressure on foundations not to exceed, in tons per square foot:

Soft clay	1
Ordinary clay and dry sand mixed with clay	2
Dry sand and dry clay	3
Hard clay and firm, coarse sand	4
Firm, coarse sand and gravel	6

Masonry.—Working pressure in masonry not to exceed, in tons per square foot:

Common brick, Rosendale-cement mortar	10
Common brick, Portland-cement mortar	12
Hard-burned brick, Portland-cement mortar	15
Rubble masonry, Rosendale-cement mortar	8
Rubble masonry, Portland-cement mortar	10
Coursed rubble, Portland-cement mortar	12
Fist-class masonry, sandstone	20
First-class masonry, limestone	25
First-class masonry, granite	30
Concrete for walls:	
Portland cement 1–2–5	20
Portland cement 1–2–4	25

Pressure on Wall-plates.—The pressure of beams, girders, wall-plates, column bases, etc., on masonry shall not exceed the following, in pounds per square inch:

On brickwork with cement mortar	200
On rubble masonry with cement mortar	200
On Portland-cement concrete	350
On first-class sandstone	400
On first-class limestone	500
On first-class granite	600

[1] Sullivan Machinery Co., *Bull.* No. 71-A.
[2] "Specifications for Structural Work on Buildings," A. S. M. E.

Costs of Some Metallurgical Plants[1]

Character of plant	Capacity per 24 hours	Cost
Iron blast furnace	300 tons of pig iron	$650,000
Acid bessemer with four cupolas and hot-metal reservoir.	2000 tons of steel	900,000
Acid open hearth, ten 50-ton furnaces.	1000 tons of steel	1,500,000
Basic open hearth, ten 50-ton furnaces.	1000 tons of steel	1,650,000
Rolling mill	Starting with ingots 20 in. square, weighing about 5000 lb., consisting of 36-in. blooming mill and 28-in. structural mill.	1,250,000 to 1,500,000
Copper smelting and converting.	Partial pyritic smelting of 1000 tons of ore to 100 tons of 45 per cent. matte.	1,250,000
Lead smelting	500 tons of mixed lead ore	250,000
Parkes desilverizing	100 tons of lead bullion	250,000
Moebius electrolytic parting	30,000 oz. of doré bullion	20,000
Electrolytic copper refining, multiple process.	100 tons of copper, from pig to wire bars.	500,000
Zinc smelting	100 tons of blende, not making sulphuric acid.	375,000
Stamp milling[2]	100 tons per day	50,000
Cyaniding[2]	100 tons per day	100,000

Cost of Metallurgical Work[3]

Cheapest type of mill in Joplin district, capacity 50,000 tons annually, construction cost, 12 to 16 cts. per ton of annual capacity.

Joplin mill designed for concentration of mixed sulphide ore, 15,000 tons annual capacity, 67 to 80 cts. per ton.

San Juan mill, capacity 75,000 tons per year, cost per ton $1.33.

Wet concentration mills of Boston Consolidated Copper Co., 1,000,000 tons capacity, cost about $1.50 a ton.

Garfield mill of Utah Copper Co., capacity 2,200,000 tons, cost per ton $1.85.

Ohio Copper Co., capacity 1,000,000 tons, cost per ton $1.50.

The above are for wet concentrating mills.

Magnetic Separating Plants

New Jersey Zinc plant, 300,000 tons capacity, cost $1.75 per ton. Smaller plants are 15,000 tons capacity, cost $3 to $4 a ton.

Copper Smelting Works

Blast-furnace plant, no roasting furnaces, annual capacity 330,000 tons, cost $1.70 per ton.

Balakalala, capacity 437,500 tons, cost $2.25 per ton, of which 25 cts. was for the converter plant.

Washoe plant, capacity 3,000,000 tons, cost $3.56 per ton.

[1] Hofman, "General Metallurgy," p. 888.
[2] H. A. Megraw, private notes.
[3] By W. R. Ingalls in Engineering and Mining Journal, July 2, 1910.

CONSTRUCTION COSTS, BELMONT MILL

	Excavation, concrete walls, and foundations	Floors and machinery foundations	Buildings		Machinery, including erection, piping, wiring, belting, etc.	Totals
			Frames	Covering		
Crusher plant	$5,760.72	$2,527.58	$2,230.72	$1,476.69	$21,174.96	$33,170.67
Inclined conveyor	166.41	238.02	1,771.75	585.19	3,620.79	6,382.16
Battery bins	399.00	489.70	....	2,067.69	3,475.14	6,431.53
Stamps	....	8,797.82	....	....	36,873.06	45,670.88
Tube mills and classifiers	....	3,180.95	....	....	40,127.89	43,308.84
Callow cones	....	26.02	....	....	856.63	882.65
Concentrating plant	....	1,663.23	....	....	11,356.35	13,019.58
Concentrate house	76.80	449.69	354.80	623.27	602.10	2,106.66
Dorr thickeners	....	11,297.98	....	....	15,034.53	26,332.51
Circulating system	....	147.81	....	....	6,846.05	6,993.86
Air agitation	261.71	3,987.80	....	....	25,257.89	29,507.40
Clarifying	....	1,829.63	....	....	8,573.87	10,403.50
Precipitation system	395.00	44.05	....	....	29,581.02	30,020.07
Briquetting plant	....	....	....	....	1,589.49	1,589.49
Air compressor	....	1,084.39	....	....	7,094.52	8,178.91
Filter plant	....	4,456.68	....	....	30,104.50	34,561.18
Refinery	2,473.84	1,552.23	2,200.17	2,292.80	7,548.79	16,067.83
Boiler plant and fuel-oil system	571.56	90.97	401.25	531.11	7,606.28	9,201.17
Tank-heating system	....	9.56	....	....	3,362.39	3,371.95
Transformer house	91.83	101.05	428.69	213.07	4,804.89	5,639.53
Lime house	11.00	....	....	753.30	305.85	1,070.15
Machine shop	1,297.66	843.01	1,138.73	1,191.93	339.36	4,810.69
Storeroom	511.55	1,509.60	1,305.84	1,315.78	152.04	4,794.81
Inclined railway	133.25	....	432.70	203.41	379.51	1,148.87
Mill building	39,645.45	6,757.60	45,493.48	19,607.14	9,020.51	120,524.18
Total	**$51,795.78**	**$51,085.37**	**$55,758.13**	**$30,861.38**	**$275,688.41**	**$465,189.07**

Highland Boy plant, capacity 300,000 tons, cost $3.23 a ton.

Garfield plant, capacity 800,000 tons, cost $7.50 per ton, but this included a large amount of land secured to protect against smoke suits.

Lead Plants

Modern lead smelting works, capacity 330,000 tons, cost $2.30 to $3.00 per ton. A lead desilverizing refinery, capacity 30,000 tons of base bullion, cost about $6.66 per ton.

Zinc Smelting Works

Zinc smelteries in natural gas field in Kansas and Oklahoma, capacity 25,000 tons annually, cost $7.00 per ton.

Plant in the same field, of superior design and construction, cost $10.00 per ton.

Plant to burn coal with gas producers and regenerative furnaces in Europe, figured to cost $15 per ton. Same plant in United States would probably have cost $17.50 to $18.00, but actual constructions have run as high as $20.00 per ton.

Sulphuric Acid Works

Sulphuric acid plant to be added to zinc smeltery, costs $5 to $6 per ton.

Miscellaneous

Tennessee Copper Co., acid plant, annual capacity 168,000 tons of acid, cost per ton of capacity $10.00.

Randfontein Central mill, capacity 150,000 tons per month, cost per ton $4.80.

Moctezuma, capacity 2000 tons per day, cost $1.37.

Federal Lead, capacity 2400 tons per day, cost $1.03.

Southeastern Missouri in general, $1.26.

Wetherill magnetic separating plant, capacity 100 tons per day, cost $2.05.

Blake electrostatic, capacity 100 tons per day, cost $1.37.

Wilfley roasting process, capacity 100 tons per day, cost $1.37.

Mexico silver-gold cyaniding plant, $3.40 per ton.

Cyanide Plant Construction

Bearing out the estimate of $1000 per ton of daily capacity as the cost of constructing a cyanide plant, the figures on p. 464 were given in the *A. I. M. E. Bulletin* for September, 1915.

The general subject of mill construction costs for the amateur was covered by HARRY T. CURRAN in the *Engineering and Mining Journal* of Aug. 14, 1915, so well that there seems to be nothing to add to his article, which is herewith reproduced.

Mill-construction costs are widely variable and the subject is a broad one. No two mills are alike, nor will their construction be carried on under the same conditions, yet the construction work itself is much the same in all. The figures given in this article are taken from my field notes and by modification they can be applied to any similar work.

The results of laborious search into metallurgical literature for mill-construction data are discouraging at the best. Little has

been written on the subject, and the operator is prone to place too much reliance on "general figures," which in varied modern practice comprise the last word in unreliability. General figures are useful, however, in rough preliminary estimations. After it has been determined just what kind of a plant is needed, the site selected and drawings made, a thorough organization of plans should be established and every detail gone over in the mind's eye.

Preparation of Costs of Material.—The first step is to estimate the yardage to be excavated, the amount of masonry or concrete work required, and then a complete list of all material should be made. The tendency is to overlook a multitude of small things which have considerable value in the aggregate. To the machinery specifications should be added a complete list of lumber, doors, windows, all hardware down to nails, pulleys, belts, lime, sand, broken rock—in fact everything that goes into the construction. The cost and weight of this can readily be determined by consulting reliable dealers and adding the necessary freight charges.

Planning the Preliminary Work.—The next step should be the working out of a thorough development plan and an estimate of its cost. Everything should be made ready, so that when actual construction starts there will be neither confusion nor delay. The cost of this work is considerable and it is often neglected, with the consequent addition of excessive costs to some other part of the work. A great amount of future trouble and worry can be avoided by a careful planning for a few important features, which will be mentioned.

Unloading facilities and material and tools to do it with should be provided. A good road to the plant should be built and convenient deliveries arranged for. It is a noticeable fact that many a well-constructed mill has such poor facilities for receiving supplies that the extra cost for a year would probably build everything needed to make such work easy and cheap. Ample room ought to be set aside for timber yards; and all lumber should be marked and piled so that a glance will determine just what part of the job it was bought for.

A handy place should be marked off for a storage house and its cost estimated. It is surprising what a number of small things will be lost or misplaced without such storage. Roomy framing plots, as level as possible, should be marked off and handy places for machinery storage determined, keeping in mind pieces which will be first used and their situation. The supply of gravel, sand and rock must be looked into and arrangements made for its cheap delivery at any point. All details for disposing of rock and earth excavated with the least possible amount of handling should be planned.

The labor question must be studied and complete arrangements made for the comfort of the men. Their efficiency will vary directly with the conditions of their surroundings. Recently, in the West, a so-called mining man who had never given human nature a moment's thought attempted to build a mill in

an out-of-the-way place with no fit accommodations for anyone but himself. The results were disastrous for the company. Good men could not be kept and the mill was finished up at an excess in cost of more than $50,000. Some of the tanks collapsed on their foundations with the first filling.

The cost of all this preliminary work can be estimated by the man on the ground; it averages from 5 to 10 per cent. of the total. If it is neglected, confusion and delays throughout the job are the inevitable result. Good organization is just as essential to the construction of a plant as to its operation.

Consideration of Erection Costs.—Erection costs are variable and can only be obtained by experience or by comparison with other jobs. If all necessary steps are taken to avoid delays estimates can be made dependable within reasonable limits. Fixed rules cannot be given for this part of the work. They will vary with the wages, efficiency of labor, climatic conditions and the experience of the man in charge. However, if the rules given in this article are applied for summer work in the United States, the estimate will come approximately close to actual cost. Labor wage is based on the average paid in Western mining camps.

Superintendence can be figured when conditions are known, and will average, including cost of plans, from 3 to 5 per cent. of the total. Excavation by picking, shoveling, and hauling average earth in wheelbarrows, moving 100 ft., will cost about 45 cts. per cubic yard; add one-third of hourly wage of laborer for every additional 100 ft. Where mine cars can be used to advantage this may be cut to 35 cts. per cubic yard, moving 100 ft.; add one-fifth of hourly wage for every additional 100 ft., which covers placing the track. Breaking rock by hand—like hauling conditions—will cost from $1.25 to $1.75 per cubic yard, with 100 ft. haul. It will cost a few cents more per yard than in earth work for every additional 100 ft. There are so many unknown quantities entering into excavating that these figures are only roughly approximate.

Masonry and Concrete Construction.—Rubble masonry will average $5 per cubic yard, using cement mortar. A mix of 1 part of portland cement to 5 parts of sharp, clean sand will give good results. Such walls will average about 15-in. courses and will require from 1/4 to 1/3 cu. yd. of mortar per cubic yard of wall. Concrete work can be figured to a nicety when conditions are known. With a mechanical mixer $1 a yard will cover the cost of mixing and placing in the average mill. On a large job it is well to determine just what mix is required with the material used. The duty of the sand is to fill the voids in the broken rock and, when the two are mixed, the resultant voids should be filled with cement. It is well to allow 10 per cent. excess in each case, but there is nothing gained by using a richer mix for retaining walls and foundation. However, if a weaker mix is desired it can be obtained by puddling instead of cutting down the proportion of sand and cement. In forms of any size puddling is good practice and the strength of the con-

crete is by no means decreased. Clean, firm rock should be used and the edges should not touch. On the average mill job concrete will not cost more than $7 per cubic yard for large forms, $8 for medium, and $10 for small and heavy-duty machine foundations, including the cost of the forms. By using old iron, reinforced concrete can be made for 50 cts. per yard more. Floors with a 5-in. base and 1-in. covering will average from $10 to $14 per cubic yard.

Unloading and hauling depend upon conditions. There will be a fixed average charge of from 30 cts. to 40 cts. per ton. Small pieces should be handled for less, but large unyielding pieces, such as a tube mill, can easily cost to $1 per ton. Probably 75 cts. per ton-mile would be a good average for hauling on any kind of a decent road and grade. By consulting local freighters these things can be definitely settled. The accompanying curve shows the variable cost of hauling on different grades. For example, consider 50 cts. per load as a cost unit, representing a reasonable cost per mile on level roads, so that a comparison of costs on different grades can be found.

Carpenter work with a well-organized crew of mill-wrights will average about $21 per M, for framing and erecting; $12 to $15 per M, for siding and roofing and $2.50 per M for shingles or 75 cts. to $1 per square for corrugating iron roofing and siding. With a picked-up local crew, $28 to $31 per M, for framing and erecting, $19 per M, for siding and roofing and $2.50 per M for shingles or $1.25 per square for iron, will be the average figures. The nails required in this work per M will be about as shown in the table.

Nails Required in Erection

	D	Lb.
Siding and roofing	8	18–21
Flooring (1-in. material)	8	28–32
Flooring (2-in. material)	20 or 30	20–25
Studding, etc.	10	14
Shingles (per 1000)	4	6

Assembling and erecting machinery depends upon the nature of the machinery. A good point to emphasize here is that poorly stored machinery may easily add several dollars per ton to erection costs. An experienced engineer will size up the job and divide the material into different classes. It is then usually figured on a tonnage basis. Generally speaking, the heavier the piece the less the erection cost per ton. Steel tanks over 3/8 in. thick can be erected for $35 per ton; for 3/8 in. or less from $40 to $45 per ton. To place engines, stamps, crushers, pumps, to line up shafting, set electric motors, including wiring, etc., about $45 per ton of iron. To set up concentrating machinery, classifiers, filters, etc., from $50 to $65 per ton. These figures cover the necessary carpenter work, placing pulleys, belts, and

adjustments. When the carpenter work is figured separately, these figures are high. Under these conditions it will cost from $25 to $30 per ton of iron to place engines, stamps, crushers, lineup shafting, etc. To set up concentrating machinery, classifiers, filters, etc., from $30 to $45 per ton. This of course includes placing pulleys, belts, and adjustments. The pipe work in the average mill will cost from $40 to $45 per ton. Erecting wooden tanks costs about $12 per M. Reduction works constructed wholly of steel are now becoming popular where the winters are not too severe. Framework of steel can be erected for $12 to $15 per ton by contract. A good contractor with a crew of construction men will make money at these figures. However, the amateur will do well if he shades the figures at all.

Recently the construction of a 50-ton combination concentrating and cyanide plant came under my notice. The contract was taken for just a little under $30 per M, and the same price per ton for machinery erection, which also included all foundations and concrete work. The total cost of the mill was around $30,000, but it is just under a finished product in every way and is bound to give considerable trouble that will eventually cost more, not considering delays, than the extra thousand or two dollars it would have taken to make it a finished mill in the first place.

Small items are important and there are a number of them. Considerable timber is required for staging and a number of unavoidable losses must be allowed for. The building should be painted, fire protection and heating arranged and office and laboratory equipment bought.

Cost of Making Alterations.—The expense of the breaking-in period and necessary alterations are often overlooked. Here we have the personal equation entering. It is a bet by the designer and constructor on his own ability. It is a good idea to allow 10 per cent. of the total cost for possible changes, while any excess is often useful to cover the expense of unavoidable delays. I have in mind two mills, designed by two well-known metallurgists, where the starting-up period took in one case 5 per cent. of the total expenditure and 15 per cent. in the other. The operator has a problem different from that of the man who follows construction only. When the former designs and constructs a mill he must worry through the breaking-in period and come out with a mill that is satisfactory in every way. On the other hand, the construction man generally has a contract and his responsibility ends by turning over a mill that is up to specifications, which may mean a good mill or a very poor one from the operator's standpoint.

Difficulties of Winter Construction.—In the northern United States winter work is a tough undertaking at its best and should be avoided if possible. With an average winter the excess cost will easily foot up to 33 per cent. of the total labor expenditure. With an open, mild winter these figures are high, but with a cold, snowy winter they may easily reach 50 per cent. Concrete

work often costs 35 per cent. more, as complete arrangements must be made for heating and protecting against frost until after the preliminary set. After 12 hours, freezing can only retard the final set, but cannot injure the concrete.

A brief description of methods used in a winter concrete job may be of interest. A steam coil 12 × 12 ft. was made out of 2-in. pipe spaced 1 ft. apart, and perforated every 6 in. with 3/16-in. holes. This made it possible to keep plenty of broken rock heated ahead of the mixer. Barrels were arranged on the mixer platform so that the water could be heated to the boiling point with steam. A 10 per cent. salt solution was made, which in no way seemed to damage the concrete. The sand was not heated. Live steam was turned into the forms before pouring, sufficient time being allowed to draw the frost a few inches. Large forms were simply well covered with canvas after filling; the concrete stayed above the freezing point for a couple of days even in the coldest weather. Small forms were protected by steam hose and fires for 12 hours. Calcium chloride is probably better than sodium chloride, since its solution freezes at a lower temperature and it also increases the waterproof quality of the concrete. It has been proven that concrete with 2 per cent. of calcium chloride gives the best resistance. More than 2 per cent. of it unduly increases the speed of setting and weakens the concrete. Since from 10 to 15 per cent. of water is used in mixing concrete, a 2 per cent. mix would be given by using a 15 or 20 per cent. solution. A 20 per cent. sodium-chloride solution freezes at about 7°F., while a 20 per cent. calcium-chloride solution will not freeze until it reaches about the zero mark.

On a winter job of any size an inclosed framing shed will pay for itself many times over. It is not only useful during the framing period, but is a happy addition on a bitter cold day during the erecting period when the carpenters would otherwise have to be laid off. There are always launders, doors, plate beds, or a multitude of small things that they can work at under protection from the weather. When the mill is finally under cover it can be kept comfortable and the work will go on much more efficiently.

Expense of Rebuilding Old Mills.—Remodeling old mills is in a class by itself and each case presents a special problem depending upon the extent of the work and the condition of the mill. Like a new mill the cost of excavating, concrete, machinery, etc., can be rather accurately figured on, but the amount of hardware and lumber that can be used again and the amount of new material required is often misleading. The carpenter work and assembling of machinery will generally cost twice as much as in a new plant. It is a tearing down and building up process for which no rules can be given.

The main causes for underestimates are:

Guess work, lack of good organization, false economy, omissions and change of plans, neglect of preliminary work, too much reliance placed on general figures, and inefficiency of labor resulting from surroundings. Under unavoidable circumstances

Ultimate and Elastic Strengths of Materials [1]

Metals (Kimball and Barr)

Material	Ultimate strength (U)			Elastic strength (E. L.)			Direct coefficient of elasticity (E)	Transverse coefficient of elasticity (Es)
	Tension	Comp.	Shear	Tension	Comp.	Shear		
Cast iron	20,000	95,000	20,000	10,000[1]	25,000	8,000	15,000,000	6,000,000
Malleable iron	35,000	42,000	20,000	....	....	....	....	....
Wrought iron	55,000	....	40,000	30,000	28,000	22,000	28,000,000	10,000,000
Steel, 0.15 carbon	63,000	....	48,000	42,000	40,000	....	30,000,000	10,000,000
Steel, 0.50 carbon	80,000	....	57,000	48,000	46,000	....	30,000,000	10,000,000
Steel, 0.70 carbon	89,000	....	60,000	53,000	53,000	....	30,000,000	10,000,000
Steel, 0.80 carbon	103,000	....	80,000	57,000	63,000	....	30,000,000	10,000,000
Steel, 0.96 carbon	118,000	....	83,000	69,000	71,000	....	30,000,000	10,000,000
Steel, boiler plate	60,000	....	48,000	30,000	....	....	30,000,000	....
Crucible steel	116,000	....	....	80,000	80,000	....	31,000,000	12,400,000
Steel castings	50,000	....	40,000	30,000	30,000	....	25,000,000	....
Nickel steel	100,000	....	....	60,000	....	....	31,000,000	....
Copper castings	22,000	60,000	....	6,000	....	....	12,000,000	....
Rolled copper	31,000	....	....	6,000	....	....	15,000,000	....
Brass castings	20,000	12,000	....	....	....	....	10,000,000	....
Bronze, gun metal	35,000	....	....	....	....	....	12,000,000	....
Bronze, phosphor	50,000	....	....	20,000	....	....	14,000,000	....
Tobin metal	80,000	....	....	55,000	....	....	....	....
Aluminum castings	15,000	12,000	12,000	6,500	3,500	....	11,000,000	....

[1] Pierce and Carver's, "Tables for Engineers." See also p. 473.

may be mentioned unexpected strikes or inefficient labor, bad-weather delays and the failure of railroads or supply houses to deliver material as expected.

Any reputable machinery house will give valuable information. Nearly all have one or more experienced engineers and will gladly go into all details with the buyer. It is a mistaken idea to think that they let their responsibility end with the last car of machinery that leaves their plant. There are plenty of would-be metallurgists who are always willing to build a plant for half the bid of a reputable house, but without exception they are a most expensive "economy." This also applies to the manufacturer of an untried innovation. Almost without exception a small mining company cannot afford to experiment with such things. If there is merit in the innovation the larger companies will soon pick it up and demonstrate it. If the plans are followed, a good organization maintained and efficient labor secured, the figures will be found a little higher than actual costs. Sectionalized machinery for mule-back haulage cannot be erected at these prices.

Effectiveness of Wood Preservatives

The relative efficiencies of certain widely used wood preservatives were recently tested by the U. S. Department of Agriculture (*Bull.* No. 227).

The tests were made by the Petri-dish method. The quantities mentioned are sufficient to stop growth in a cubic foot of culture medium.

For Fomes annosus	Pounds	For Fomes pinicola	Pounds
Coal-tar creosote:		Coal-tar creosote:	
Fraction II	0.14	Fraction III	0.08
Sodium fluoride	0.16	Fraction IV	0.08
Cresol calcium	0.09–0.18	Fraction II	0.09
Coal-tar creosote:		Sodium fluoride	0.09
Fraction I	0.19	Wood creosote	0.13
Fraction III	0.20	Coal-tar creosote:	
Zinc chloride	0.31	Grade C	0.14
Coal-tar creosote, Grade C	0.34	Fraction I	0.14
Water-gas tar distillate (sp. gr. 0.995)	0.41	Avenarius carbolineum	0.19
		Zinc chloride	0.47
Wood creosote	0.41	Hardwood tar	0.47
Hardwood tar	0.78	Coal-tar creosote:	
Coal-tar creosote:		Fraction V	4.87
Fraction IV	2.06	Copperized oil	Over 25
S. P. F. carbolineum	2.8	United Gas Improvement Co., 1.07 oil	Over 25
Avenarius carbolineum	3.27	Nonesuch special	Over 25
Coal-tar creosote:			
Fraction V	20.59		
Copperized oil	25.0		
United Gas Improvement Co., 1.07 oil	Over 25		
Nonesuch special	Over 25		
Sapwood antiseptic	Over 25		

Cement Compositions

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	NaKO
Portland[1]	19–26	4–11	0–4	58–67	0–4	0–1.75	0–3
Rosendale[1] (natural)	27.30	7.14	1.80	35.98	18.00	......	6.80
Slag cement[1]	28.95	11.40	0.54	50.29	2.96	3.41	......
Hydraulic[2]	21.60	3.20	0.65	61.00	0.85	0.60	H_2O = 12.00
Grenoble[3] natural[2]	26.30–27.30	9.30–12.70	......	50.80–55.00	0–3.00	......	......

Strength of Common Materials[4]

Material	Ultimate strength (*U*)	
	Tension	Compression
Bricks, best hard	400	12,000
Bricks, light red	40	1,000
Brickwork, common	50	1,000
Brickwork, best	300	2,000
Cement, Portland, 1 month old	400	2,000
Cement, Portland, 1 year old	500	3,000
Concrete, Portland	200	1,000
Concrete, Portland, 1 year old	400	2,000
Hemlock	6,000	4,000
Oak, white	10,000	7,000
Pine, shortleaf yellow	9,000	6,000
Pine, Georgia	12,000	8,000
Pine, white	7,000	5,500

BLOWING MACHINERY TYPES

The centrifugal blower is usually used for moving large volumes of air at pressures up to 16 oz. per square inch. Such service is that required for reverberatory furnaces or cupola furnaces. The disadvantages of the centrifugal blower are that it must run very close to rated capacity if it is to run economically, and that it cannot send blast into a choked furnace. An example of a large centrifugal blower is quoted by Hofman as being furnished by the General Electric Co., 10,200 cu. ft. of air per minute at 3¼-lb. pressure.

Turbo-blowers are multistage centrifugal blowers. The discharge from one blower forms the feed of the next, thus enabling these blowers to compete even with high-pressure blowing engines. Hofman quotes one blowing 42,000 cu. ft. of air per minute, attaining a maximum pressure of 18 lb.

[1] Benson's, "Industrial Chemistry." The Macmillan Co.
[2] J. Park, "Text-book of Practical Assaying."
[3] Said to be finest natural cement in the world.
[4] Pierce and Carver's, "Tables for Engineers."

Rotary Blowers.—Two impellers, which may be similar or dissimilar in shape attached to parallel shafts, revolve in opposite directions. The impellers are in tangential contact with each other and with the casing and hence draw in a fixed volume of air and discharge it on the opposite side. Consequently they are known as positive blowers. They are most effective working at from 1 to 4 lb. pressure. The ROOTS blower has two impellers whose surfaces are epicycloidal curves. The CONNERSVILLE also has this impeller form. The BAKER has one large impeller with two vanes, and two small revolving drums for valves. The STURTEVANT is a very complicated two-impeller machine.

Blowing Engines.—These are of the double-acting piston type and are used for converters, iron blast furnaces, and a few copper furnaces requiring very high pressures.

Testing Blower Capacity

Experiments at the Mission School of Mines by ELMO H. HARRIS have shown that the most reliable method for testing large blowers is by passing the air current through large orifices. A 30-in. orifice will pass about 25,000 cu. ft per min. under 4-in. water pressure. Where very large blowers are to be tested he advises setting several orifices in a conduit wall (Missouri *School of Mines Bull.*, November, 1915). The essential tables are:

Water gage, inches, i	McGill coefficient orifice 3½ in.	Coefficients C for large orifices						
		Round			Square			
		30 in.	24 in.	18 in.	30 in. × 30 in.	24 in. × 24 in.	18 in. × 18 in.	18 in. × 30 in.
1	0.599	0.604	0.599	0.597	0.628	0.607	0.598	0.602
2	0.597	0.602	0.579	0.596	0.626	0.605	0.596	0.600
3	0.596	0.601	0.596	0.594	0.625	0.604	0.595	0.599
4	0.595	0.600	0.595	0.593	0.624	0.603	0.694	0.598
5	0.594	0.599	0.594	0.592	0.623	0.601	0.593	0.597

The above coefficients are to be applied to get the weight Q per second, of air passing by formula as follows:

For round orifices $Q = C \times 0.1639D^2\sqrt{\frac{i}{t}p}$

For rectangular orifices $Q = C \times 2.413a\sqrt{\frac{i}{t}p}$

Q = Weight of air in pounds per second.
i = Water gage in inches.
t = Absolute temperature (Fahrenheit) = 460 + (Thermometer reading F.).
p = Absolute pressure back of orifice in pounds per square inch = barometer pressure + $0.036i$.
D = Diameter of round orifice in inches.
a = Area of rectangular orifice in square feet.

SECTION X

GENERAL METALLURGY

PROCESSES KNOWN BY THEIR INVENTORS' OR BY NON-DESCRIPTIVE NAMES

Aczolling—the treatment of timber with a mixture of metallic ammoniates with an antiseptic acid (derivative of phenol or naphthalene).

Augustin process for silver extraction consists of chloridizing-roasting; leaching with hot solutions of common salt in wooden vats; precipitating the silver on copper and casting into silver bars; precipitating the copper on scrap iron and casting it into shot to be used again.

Bessemer process—the production of steel by blowing air through molten pig iron. Also, by analogy, the enrichment of copper matte by blowng air through it when molten. See Converting.

Betts lead refining process—an electrolytic process using $PbSiF_6$ acidulated with HF as the electrolyte.

Boss process for silver extraction is a continuous pan-amalgamation process.

Converting—the process invented by PIERRE MANHÉS in which air is blown through molten copper matte in the presence of free silica. The iron is oxidized to FeO which forms a slag with the silica; the sulphur is oxidized and goes off as SO_2. After the iron is practically oxidized, copper is formed thus:

$$Cu_2S + 3O = Cu_2O + SO_2$$
$$2Cu_2O + Cu_2S = 6Cu + SO_2.$$

Also applied to the Bessemer process of steel manufacture.

Diehl process—a modification of the cyanide process in which cyanogen bromide is added to the leaching solution.

Dumoulin process—copper is deposited on a rotating mandrel and this copper is later stripped off as a long strip, which is then drawn into wire without recasting.

Elmore process—a flotation process. See Flotation for full description.

Gutzkow's process—a modification of the sulphuric-acid parting process for bullion containing large amounts of copper. A large excess of acid is used; the silver sulphate is then reduced with charcoal or, in the original process, ferrous sulphate.

Hayden process—for copper refining. There is but one true cathode and one anode in the tank, a large number of plates of unrefined copper being placed between and parallel

to them. The side of each plate toward the cathode then acts as anode, while copper is deposited on the side of each plate toward the anode, until the entire plate has moved over by the amount of its own thickness. This is the so-called series method of refining.

Höpfner process—Copper Recovery.—A solution of cuprous chloride in sodium or calcium chloride is used to dissolve copper sulphides. The solution is then electrolyzed in tanks with diaphragms. The anodes are copper, the cathodes pure copper. Copper is deposited from the cuprous-chloride solution, and cupric chloride regenerated.

Hunt's process—compiled by Bertram Hunt for treating precious metal ores containing copper or zinc, using an ammoniacal cyanide solution and recovering ammonia by boiling. Process may more truly be said to have been devised and perfected by MOSHER.

Hunt & Douglas process—consists in roasting matte carrying copper, lead, gold and silver at a very low temperature, forming copper sulphate and oxide but not silver sulphate. This product is leached with dilute sulphuric acid for copper. The resulting solution is treated with calcium chloride and the copper precipitated as subchloride by passing SO_2 through the solution. The cuprous chloride was then reduced to cuprous oxide by milk of lime, regenerating calcium chloride, and the cuprous oxide was smelted.

Kiss process—about the same as the PATERA process (which see below) except that calcium hyposulphite was used for leaching the ore, and calcium polysulphide for precipitating the silver.

LeBlanc process for soda making—

$$2NaCl + H_2SO_4 = Na_2SO_4 + 2HCl$$
$$Na_2SO_4 + 2C = Na_2S + 2CO_2$$
$$Na_2S + CaCO_3 = Na_2CO_3 + CaS$$

Lohmannizing—a process by which a protective zinc coating is amalgamated to the base-metal sheet. Details of the process not made public.

MacArthur-Forrest cyanide process—the original successful commercial process.

Marriner process—a modification of the cyanide process in which the ore is dead roasted, all of it ground to slime, and the resulting product treated by agitation.

Miller process of parting gold and silver by conducting chlorine gas into the molten metal. The silver and other base metals are chloridized and come to the top of the bath.

Moebius process—for parting gold and silver. The electrolyte is silver nitrate with a little nitric acid. In the original process the silver was deposited on an endless moving silver belt, from which it was constantly removed by revolving brushes.

Murex process—see under "Flotation," p. 392.

Parkes process—lead refining by the addition of zinc to

molten argentiferous lead. The zinc and silver rise to the surface of the bath as a scum, which is then taken off and afterward distilled to drive off the zinc.

Patera process consists in a chlorizing-roasting; leaching with water to remove base metals (some silver is dissolved and must be recovered); leaching with sodium hyposulphite for silver; precipitation of silver by sodium sulphide. The process was first carried out by VON PATERA at Joachimsthal.

Patio process is one for the recovery of silver by amalgamation in low heaps with the aid of salt and copper sulphate (*magistral*). Thorough mixing is obtained in the usual form by having horses or oxen tread the mass.

Pattinson process—recovery of the silver from argentiferous lead by fractional crystallization of lead crystals out of a silver-lead eutectic. Seldom used now except in conjunction with the PARKES process (*q.v.*).

Peirce-Smith—basic-converting process—converting copper matte in a magnesite-lined converter. The iron of the matte is fluxed by silica added before the process begins.

Pelatan-Clerici process is a continuous process of dissolving silver or gold in cyanide solution and simultaneously precipitating the precious metals in mercury in the same vessel, an electrical current assisting precipitation.

Powellizing—a process of wood treatment consisting in impregnating the wood with a saccharin solution. It hardens the wood, and appears to fireproof it somewhat.

Randolph process—a modification of the series process of copper refining in which the electrodes lie horizontally, the top surface of each one acting as anode, the lower as cathode. Theoretically it has the advantage of extremely low metal losses and great purity of copper. Practically, it is too difficult to right matters in a tank after a short circuit. See HAYDEN series and SMITH processes.

Reese River process—pan amalgamation with previous roasting.

Rozan process (LUCE-ROZAN process)—Pattinsonizing with steam.

Russell process—about the same as the PATERA (*q.v.*) except that cuprous-sodium hyposulphite is used in addition to the sodium hyposulphite.

Series Copper-refining Process.—See HAYDEN, SMITH and RANDOLPH processes.

Sherardizing—a process of cold galvanizing. The cleaned parts are tumbled in zinc dust, which coats them as in ordinary galvanizing. Cannot be used for parts which would be injured by the tumbling.

Siemens & Halske method of copper recovery.—Copper sulphides are dissolved by solutions of ferric sulphate containing free sulphuric acid.

$(H_2SO_4) + Cu_2S + 2Fe_2(SO_4)_3 = 2CuSO_4 + 4FeSO_4 + (H_2SO_4)$

The solution is then electrolyzed in a tank having a diaphragm. Copper is deposited and ferric sulphate regenerated.

Siemens-Martin process—the production of steel in a reverberatory furnace by oxidation of the impurities by oxides added (either the rust on scrap, or mill scale, or pure ores). It may be conducted either on an acid or a basic lining.

Smith process—a variation of the series system of copper refining in which the plates are placed horizontally, the top surface of each one acting as cathode, the lower as anode. Linen diaphragms must be placed between the plates to catch the slimes. These diaphragms break and allow the slimes to drop on the cathode, and it is impossible to remedy any short circuits in the tank without dismantling the tank.

Solvay process for soda manufacture—

$$NaCl + HNH_4CO_3 = HNaCO_3 + NH_4Cl$$
$$2NH_4Cl + MgO = MgCl_2 + 2NH_3 + H_2O$$
$$2HNaCO_3 = Na_2CO_3 + CO_2 + H_2O$$
$$CO_2 + NH_3 + H_2O = HNH_4CO_3.$$

Spellerizing—subjecting the heated bloom to the action of rolls having regularly shaped projections on their working surface, then subjecting the bloom while still hot to the action of smooth-faced rolls. The surface working is said to give a dense texture to pipe made from the bloom, adapting it to resist corrosion.

Thomas-Gilchrist process—bessemerizing (*q.v.*) pig iron high in phosphorus and low in S; in a converter lined with calcined dolomite. The slags formed consist of a basic calcium phosphate which is used for fertilizer.

Thum-Balbach process—a silver-refining process using carbon cathodes, doré anodes and a silver-nitrate nitric-acid electrolyte. The silver is scraped off the bottom as crystals.

Washoe process—for silver extraction. Consisted in wet crushing and pan amalgamation without previous roasting. Named for the district in which it was first carried on.

Weldon's process for making chlorine—

$$MnO_2 + HCl = MnCl_2 + Cl_2 + H_2O$$
$$MnCl_2 + Ca(OH)_2 = Mn(OH)_2 + CaCl_2$$
$$Mn(OH)_2 + Ca(OH)_2 + O \text{ (from air)} = CaMnO_3 + 2H_2O$$
$$2Mn(OH)_2 + Ca(OH)_2 + 2O = CaMn_2O_5 + 3H_2O$$
$$CaMnO_3 + 6HCl = CaCl_2 + MnCl_2 + 3H_2O + Cl_2$$
$$CaMn_2O_5 + 10HCl = CaCl_2 + 2MnCl_2 + 5H_2O + 2Cl_2$$

Wohlwill process—a process of gold refining, using impure gold bullion as anodes and sheet gold cathodes in a solution carrying 25–30 oz. of gold and 25–30 oz. free HCl (sp. gr. 1.19) per cu. ft. If the anodes contain lead some H_2SO_4 is added. The current density is about 100 amp. per sq. ft., the potential 1 volt. The tanks usually used are porcelain. Platinum and the allied metals remain in the electrolyte, the silver settles out as chloride.

Ziervogel process—this consisted in smelting ore to an argentiferous matte; concentrating the matte to 60 or 70 per cent. Cu; grinding; roasting under such conditions of temperature

ontrol as to decompose the copper sulphate while leaving the ilver sulphate undecomposed; leaching out the silver with vater, precipitating the silver and recovering it; smelting the esidues for copper bottoms from which the gold can be ecovered.

Unstable Alloys[1]

The following metals do not form stable alloys within the mits mentioned, *i.e.*, if a mixture containing percentages of the laterials lying between the critical points is heated, there may e (though not always) an alloy produced at the time, but here will be segregation on standing.

Temperature				
		Zinc-Lead Alloys		
650°C.	Between.......	Pb = 98.76 Zn = 1.24	and	Pb = 1.14 Zn = 98.86
800°C.	Between.......	Pb = 98.70 Zn = 1.30	and	Pb = 1.57 Zn = 98.43
		Bismuth-Zinc Alloys		
650°C.	Between.......	Bi = 85.72 Zn = 14.28	and	Bi = 2.32 Zn = 97.68
750°C.	Between.......	Bi = 84.82 Zn = 15.18	and	Bi = 2.47 Zn = 97.53
800°C.	Between.......	Bi = 84.17 Zn = 15.83	and	Bi = 2.52 Zn = 97.48
		Lead-Aluminum Alloys		
800°C.	Between.......	Pb = 99.93 Al = 0.07	and	Pb = 1.91 Al = 98.09
		Bismuth-Aluminum Alloys		
800°C.	Between.......	Bi = 99.72 Al = 0.28	and	Bi = 2.02 Al = 97.98
		Cadmium-Aluminum Alloys		
750°C.	Between.......	Cd = 99.78 Al = 0.22	and	Cd = 3.39 Al = 96.61

Alloys

Aluminum.—Aluminum containing 0.05 to 0.20 per cent. of 'e is more resistant to corrosion than aluminum itself.

Aluminum-Silver Alloy.—Argental—silver substitute.

Aluminum-Zinc Alloy.—Macadamum—strong but light castigs. Patented alloy, like preceding. Composition unknown.

Argental.—Aluminum-silver.

Auer Metal.—35 per cent. Fe and 65 per cent. of the metal btained by reducing the cerium earths (Misch metal, *q.v.*).

Bismuth Alloys.—Bi, 3; Pb, 10; Sn, 5. Sticks to glass, ıelts at 170°C.

Cobalt-Chromium Alloys—Stellite.—High tensile strength, esistant to corrosion, takes high polish.

Cobalt-Chromium-Tungsten.—Harder than stellite.

[1] ROBERT'S-AUSTEN, "Introduction to the Study of Metallurgy."

Alloys

	Cu	Zn	Fe	Sn	Pb	Sb	Ni	Ag	Bi	Al	
Aich's metal	60.00	38.12	1.50								This and Sterro's metal are remarkable for their great tensile strength, 85,000 lb. per square inch.
Acid-resisting metal	83.05	6.00		10.81	0.10						Recommended for use with acid mine water.
Ajax plastic bronze	65.00			5.00	30.00						
Alkali-resisting metal			95.00				5.00				For soap factories, etc.
Anti-friction metal	5.00	85.00									
Ashberry		2.80		77.80		19.40					
Admiralty brass	61.7	36.9		1.4							Melts at 1570°F.
Babbitt's (original)	4.00	69.00		19.00	5.00	3.00					
Babbitt, hard	8.00			88.00		4.00					
Babbitt, normal	3.00			90.00		7.00					
Babbitt, soft	3.00			84.00	5.60	7.40					
Babbitt, German railways	5.60			83.30		11.10					S.A.E. specification says Sb, 9; Cu, 7 per cent.
Babbitt, Swiss railways	10.00			80.00		10.00					
Bell metal	80.00			20.00							
Berlin argentan	52.00	22.00					26.00				
Brass, cartridge	66.66	33.34									Yellow brass for plumbers use may carry up to 4 per cent. lead in this mixture. Without lead melts at about 1650°.
Brass, high	61.50	38.50									Typical brass. The high brass for naval use may carry 1 per cent. Sn.
Brass, low	80.00	20.00									
Britannia, casting	0.20			90.60		9.20					Some makers say 0.15 per cent. Mn improves the grain.
Britannia, sheet	1.50			90.60		7.80					
Britannia, spinning	1.00			94.00		5.00					
Brass solder	33.00	67.00									Or may be 50 per cent. Cu, 50 per cent. Zn.
Bronze, British coinage	95.00	1.00		4.00							
Bronze, bearing metal	80.00	7.00		13.00							
Bronze, bearing metal	90.00	7.00		3.00							

ALLOYS

	Cu	Zn	Fe	Sn	Pb	Sb	Ni	Ag	Bi	Al	
Bronze, Chinese art	74.00	10.00		1.00	15.00						
Bronze, Japanese art	82.70	1.80			4.70						
Bronze, Japanese art	71.40	6.00			5.90						
Bronze, U. S. Naval	88.00	2.00		10.00							English gear bronze is Cu 88.70, Sn 11.00, P 0.30.
Bronze, Tobin	58.22	39.48		2.30							
Coin, silver, U. S.	10.00							90.00			
Constantan	60.00						40.00				
Cupromagnesium	90.00								Mg 10.00		Used as a deoxidizer; density 8.4, melts 1290°C.
Camelia metal	70.20	10.20	0.55	4.25	14.75						
Darcet's metal				25.00	25.00				50.00		Melts at 93°C.
Delta metal	55.10	43.47	1.08		0.37						Practically same as Sterro metal.
Dewrance metal	22.2			33.3		44.5					
Duralumin	3.00						Mn 1.0	Mg 0.5		95.5	May contain some Fe and Si from the Al.
Duriron			88.00					Si 12.00			Extremely resistant to acids. Very hard. Sp. gr. 7.00. Melts 1200°C. Tensile strength, 12,000–14,000 lb. Coeff. of exp. per F.°, 0.00001565.
Fontaine-moreau's bronze	4.50	94.00	0.50								
Fusible metal											See Darcet's, Guthrie's, Lipowitz's, Lichtenburg's, Newton's, Onion's, Rose's, Wood's.
German silver (English)	61.30	19.10					Ni 19.10				
Gun metal	92.50	2.50		5.00							
Gun metal	91.00	2.00		7.00							
Gun metal	87.75	2.50		9.75							Melts at 1825°F.
Gun metal	85.00	10.00		5.00							With 3 per cent. Pb, melts at 1795°F.
Gun metal	83.00	15.00		2.00							
Gurley's metal	86.50	5.40		5.40	2.70						Used for transit frames.
Guthrie's metal				19.97	19.36			Cd 13.29	47.38		Melts at 160°F.

ALLOYS

	Cu	Zn	Fe	Sn	Pb	Sb	Ni	Ag	Bi	Al	
Hardware metal	50.00	34.90					15.00			0.10	Harness trimmings, etc. Casts well. Doesn't roll.
Hydraulic bronze	75.00	14.00		11.00							
Hydraulic bronze	83.00	5.00		5.00	5.00		2.00				For pressures up to 3000 lb. per sq. in.
Jacoby metal	5.00			85.00		10.00					
Lichtenberg's metal				20.00	30.00				50.00		Melts 94.5°C.
Lipowitz's metal				13.33	26.67				50.00	Cd 10.00	Melts 70°C.
Mackenzie's alloy					68.00	16.00			16.00		Stereotype metal
Magnolia metal				4.75	80.00	15.00			0.25		Melts at 608°C., coeff. of exp. 0.000024 per C.°.
Magnalium											
Manganin	82.12		0.57				2.29		Mn 15.02		Practically no temperature coefficient in resistance.
Mannheim gold	80.00	20.00									Practically identical with Prince's metal and Tombac.
Mannheim gold	88.00	12.00									
Monel metal	33.00		6.50				60.00			Al 0.05	U. S. Gov't. specifications for castings.
Mosaic gold	65.00	35.00									
Morin's Chinese bronze	83.00	2.00		5.00	10.00						
Muntz metal	62.00	38.00									
	60.00	40.00									
Manganese bronze	88.64	1.57	0.72	8.70	0.295						Trace of P.
Newton's metal				18.75	31.25				50.00		Melts at 94.5°C.
Needle metal	84.96	5.31		7.96	1.77						Extremely fluid.
Onion's alloy				20.00	30.00				50.00		Melts at 197°F.
Packfong	43.80	40.60					15.60				A Chinese alloy.
Pinchbeck	83.33	16.76									A cheap imitation gold.
Parr's alloy	5.00		Cr 20.00				63.00	W 2.00		Mo 5.00	Also contains Al, B, and Mn. Said to have tensile strength of 60,000 lb. per square inch and to resist acids.
Plastic bronze	65.00			5.00	30.00						

Alloys

	Cu	Zn	Fe	Sn	Pb	Sb	Ni	Ag	Bi	Al	
Platinoid	60.00	24.00					14.00	W 2.00			Sp. gr. 13.6. Coeff. of exp. 0.0000036.
Platine	43.00	57.00									
Pewter	1.42			97.00	1.65						
Phosphor bronze	80.00			10.00	10.00						Phosphorus, 0.05–0.25 per cent.
Queen's metal	3.50	0.90		88.50		7.10					
Red metal	70.00	20.00		4.00	6.00						Melts at about 1800°F.
Rose's metal				25.00	25.00				50.00		Melts at 93.75°C.
Sheffield German silver	57.00	19.00					24.00				
Silicon bronze	97.12	1.12		1.14							Also a little Si. Extremely high tensile strength.
Solder				33.33	66.67						Sp. gr. 9.4; Coeff. of exp. 0.000025; melts at 240°C.
Solder, soft for silver	28.00	11.00		4.00				Ag 57.00			
Solder, hard for silver	13.00	7.00						80.00			
Sterline	68.52	12.84	0.76		tr.	17.88					Imitation silver for forks, etc.
Sterro's metal	55.33	41.80	4.66								
Type metal				3.00	82.00	15.00					
Tobin bronze	58.22	39.48		2.30							
Tantiron			83.50		C = 1.0		Si = 15.0				Highly resistant to corrosion by acid.
Tombac, English	86.38	13.61									
Tombac, Viennese	97.80	2.20									
Solder for German silver	45.00	45.00					10.00				Melts easily, flows well.
Turbadium bronze	48.00	46.45	1.00	0.50	0.10		2.00	Mn 1.75		0.20	Used for propeller castings.
Turbine-wheel mixture	86.77	3.48		8.68	1.07						Not so likely to have blow-holes as Mn-bronze.
Trolley-wheel bronze	92.00	2.00		6.00	none						
Victor metal	49.94	34.27	0.28				15.40			0.11	Resists salt air.
Watchmaker's alloy	58.86	40.22			1.90						An imitation gold.
White brass	3–6	28–30		65.00							Good bearing in automobile engines.
Wood's metal				12.50	25.00			Cd 12.50	50.00		Melts at 60.5°C.

Cobalt-chromium-molybdenum—up to 40 per cent. W and 40 per cent. Mo suitable for high-speed steels.

Cobalt-Tin (40 Co, 60 Sn to 60 Co, 40 Sn).—Very resistant to acids, but too brittle for ordinary purposes.

Elianite.—A patented composition; withstands acids and halogens; melts at 1250°C. Probably a ferrosilicon.

High-speed Steel.—C, 0.45–.085 per cent.; Si, tr.–0.20 per cent.; Mn, 0.10–0.50 per cent.; W, 8 to 18 per cent.; Cr, 2.50–6.5 per cent.; Mo, 0–2.50 per cent.; V, 0–1.5 per cent.; Co, 0–5 per cent.

High-speed Steel (Beth. Steel Co., Paris Exposition).—C, 0.6 per cent.; Mn, 0.2 per cent.; Si, 0.1 per cent.; Cr, 4 per cent., W, 18 per cent.

Ivanium.—A patented aluminum alloy.

Kaiserzinn.—Practically britannia, which see in alloys.

Kunheim Metal.—A pyrophoric alloy containing hydrides of the cerium earth metals with magnesium and aluminum.

Macadamum.—An aluminum-zinc alloy.

Misch Metal.—Cerium, 42 per cent.; lanthanum, didymium, etc., 57 per cent. (These figures are approximate only).

Mushet Steel.—C, 2 per cent.; Mn, 1.75 per cent.; Si, 0.75 per cent.; Cr, 0.4 per cent.; W, 5.5 per cent.

Phonoelectric Wire.—See silicon-bronze in preceding table.

Pyrophoric Alloys.—Cerium-iron mixtures.

Stellite.—A white noncorrosive extremely hard metal patented by Elwood Haynes. It consists of 10–25 per cent. Cr, 90–75 per cent. Co and may carry a little tungsten or molybdenum.

Fluxes for Soldering and Welding[1]

Iron or steel.	Borax or sal-ammoniac.
Tinned iron.	Resin or tin chloride.
Copper and brass.	Sal-ammoniac or zinc chloride.
Zinc.	Zinc chloride.
Lead.	Tallow or resin.
Lead and tin pipes.	Resin and sweet oil.
Aluminum.	Borax 96 parts, sodium bisulphate 4 parts.[2]

[1] Megraw, "Practical Data for the Cyanide Plant."

[2] Given as a Danish flux by *Brass World*, May, 1915. Seems very questionable whether it will work.

Some General Considerations Regarding Alloys

A pure metal is always softer than its alloys; it is usually more malleable and ductile; the expansion of alloys by heat cannot be calculated from the coefficients of expansion of the constituents; the specific heat of alloys at temperatures considerably removed from the melting points is the mean of the specific heat of the metals composing them; alloys never conduct heat as well as the components; the electric conductivity is also usually lower than that of either constituent.

SHEET-ZINC GAGE

Gage number	American		Belgian		Vieille Montagne	
	Thickness, decimals of an inch	Weight per sq. ft., lb.	Thickness, decimals of an inch	Weight per sq. ft., lb.	Thickness, decimals of an inch	Weight per sq. ft., lb.
1	0.002	0.075	0.0018	0.068	0.004	0.150
2	0.004	0.150	0.0036	0.135	0.006	0.225
3	0.006	0.225	0.0055	0.206	0.007	0.263
4	0.008	0.300	0.0073	0.274	0.008	0.300
5	0.010	0.375	0.0091	0.341	0.010	0.375
6	0.012	0.450	0.0110	0.413	0.011	0.413
7	0.014	0.525	0.0128	0.480	0.013	0.488
8	0.016	0.600	0.0146	0.548	0.015	0.563
9	0.018	0.675	0.0165	0.619	0.018	0.675
10	0.020	0.750	0.0180	0.675	0.020	0.750
11	0.024	0.900	0.0217	0.814	0.023	0.863
12	0.028	1.050	0.0254	0.953	0.026	0.975
13	0.032	1.200	0.0290	1.088	0.029	1.088
14	0.036	1.350	0.0326	1.223	0.032	1.200
15	0.040	1.500	0.0364	1.365	0.038	1.425
16	0.045	1.688	0.0400	1.500	0.043	1.613
17	0.050	1.875	0.0437	1.639	0.048	1.800
18	0.055	2.063	0.0478	1.793	0.053	1.988
19	0.060	2.250	0.0509	1.909	0.058	2.175
20	0.070	2.625	0.0581	2.179	0.063	2.363
21	0.080	3.000	0.0728	2.730	0.070	2.625
22	0.090	3.375	0.0764	2.865	0.077	2.888
23	0.100	3.750	0.0800	3.000	0.084	3.150
24	0.125	4.688	0.0896	3.360	0.091	3.413
25	0.250	9.375	0.0992	3.720	0.098	3.675
26	0.375	14.063	0.1088	4.080	0.105	3.938
27	0.500	18.750	....	....	....	....
28	1.000	37.500	....	....	....	....

Wire and Sheet Metal Gages Compared[1]

Number of gage	Birmingham or Stubs' iron wire gage, inch	American or Brown & Sharpe's gage, inch	Roebling's and Washburn & Moen's gage, inch	Stub's steel wire gage, inch	British Imperial Standard wire gage, inch	Legal standard since Mar. 1, 1884, mm.	U. S. sheet and plate gage, inch	Number of gage
0000000	....	....	0.49	......	0.500	12.7	0.500	7/0
000000	....	....	0.46	......	0.464	11.78	0.469	6/0
00000	....	....	0.43	......	0.432	10.97	0.438	5/0
0000	0.454	0.46	0.393	......	0.400	10.16	0.406	4/0
000	0.425	0.40964	0.362	......	0.372	9.45	0.375	3/0
00	0.380	0.3648	0.331	......	0.348	8.84	0.344	2/0
0	0.340	0.32486	0.307	......	0.324	8.23	0.313	0
1	0.300	0.2893	0.283	0.227	0.300	7.62	0.281	1
2	0.284	0.25763	0.263	0.219	0.276	7.01	0.266	2
3	0.259	0.22942	0.244	0.212	0.252	6.40	0.250	3
4	0.238	0.20431	0.225	0.207	0.232	5.89	0.234	4
5	0.220	0.18194	0.207	0.204	0.212	5.38	0.219	5
6	0.203	0.16202	0.192	0.201	0.192	4.88	0.203	6
7	0.180	0.14428	0.177	0.199	0.176	4.47	0.188	7
8	0.165	0.12849	0.162	0.197	0.160	4.06	0.176	8
9	0.148	0.11443	0.148	0.194	0.144	3.66	0.156	9
10	0.134	0.10189	0.135	0.191	0.128	3.25	0.141	10
11	0.120	0.09074	0.120	0.188	0.116	2.95	0.125	11
12	0.109	0.08081	0.105	0.185	0.104	2.64	0.109	12
13	0.095	0.07196	0.092	0.182	0.092	2.34	0.094	13
14	0.083	0.06408	0.080	0.180	0.080	2.03	0.078	14
15	0.072	0.05707	0.072	0.178	0.072	1.83	0.070	15
16	0.065	0.05082	0.063	0.175	0.064	1.63	0.0625	16
17	0.058	0.04526	0.054	0.172	0.056	1.42	0.0563	17
18	0.049	0.04030	0.047	0.168	0.048	1.22	0.0500	18
19	0.042	0.03589	0.041	0.164	0.040	1.02	0.0438	19
20	0.035	0.03196	0.035	0.161	0.036	0.91	0.0375	20
21	0.032	0.02846	0.032	0.157	0.032	0.81	0.0344	21
22	0.028	0.02535	0.028	0.155	0.028	0.71	0.0313	22
23	0.025	0.02257	0.025	0.153	0.024	0.61	0.0281	23
24	0.022	0.02010	0.023	0.151	0.022	0.56	0.0250	24
25	0.020	0.01790	0.020	0.148	0.020	0.51	0.0219	25
26	0.018	0.01594	0.018	0.146	0.018	0.46	0.0188	26
27	0.016	0.01419	0.017	0.143	0.0164	0.42	0.0172	27
28	0.014	0.01264	0.016	0.139	0.0148	0.38	0.0156	28
29	0.013	0.01126	0.015	0.134	0.0136	0.35	0.0141	29
30	0.012	0.01002	0.014	0.127	0.0124	0.31	0.0125	30
31	0.010	0.00893	0.013	0.120	0.0116	0.29	0.0109	31
32	0.009	0.00795	0.013	0.115	0.0108	0.27	0.0101	32
33	0.008	0.00708	0.011	0.112	0.0100	0.25	0.0094	33
34	0.007	0.00630	0.010	0.110	0.0092	0.23	0.0086	34
35	0.005	0.00561	0.0095	0.108	0.0084	0.21	0.0078	35
36	0.004	0.00500	0.0090	0.106	0.0076	0.19	0.0070	36
37	....	0.00445	0.0085	0.103	0.0068	0.17	0.0066	37
38	....	0.00396	0.080	0.101	0.0060	0.15	0.0063	38
39	....	0.00353	0.0075	0.099	0.0052	0.13	......	39
40	....	0.00314	0.007	0.097	0.0048	0.12	......	40
41	....	....	....	0.095	0.0044	0.11	......	41
42	....	....	....	0.092	0.0040	0.10	......	42
43	....	....	....	0.088	0.0036	0.09	......	43
44	....	....	....	0.085	0.0032	0.08	......	44
45	....	....	....	0.081	0.0028	0.07	......	45
46	....	....	....	0.079	0.0024	0.06	......	46
47	....	....	....	0.077	0.0020	0.05	......	47
48	....	....	....	0.075	0.0016	0.04	......	48
49	....	....	....	0.072	0.0012	0.03	......	49
50	....	....	....	0.069	0.0010	0.025	......	50

[1] From Kent's "Mechanical Engineer's Pocket Book," 8th Edition, p. 30; and "American Machinist," p. 931, Dec. 5, 1912. The moral of the above table is to specify wire by mils and not by gages.

IMPURITIES IN COMMERCIAL METALS

Aluminum: Fe, 0.18 per cent.; Si, 0.17; Na, 0.05; Cu, tr. Electrolytic aluminum will carry 98.52 to 99.34 per cent. Al, and Si from 0.07 to 1.14, per cent. according to RICHARDS.

Antimony:[1] COOKSON'S: Pb, 0.041; Sn, 0.035; As, tr.; Cu, 0.04; Fe, 0.010; Zn, tr. COOKSON'S: Pb, 0.102, Sn, tr.; As, 0.092; Bi, none; Cu, 0.046; Cd, none; Fe, 0.004; Zn, 0.034; Ni and Co, 0.028; S, 0.086; Sb (by difference), 99.608. HALLETT'S: Pb, 0.669; Sn, 0.175; As, tr.; Cu, 0.038; Fe, 0.014; Zn, tr. HALLETT'S: Pb, 0.718; Sn, 0.012; As, 0.021; Bi, none; Cu, 0.046; Cd, none; Fe, 0.007; Zn, 0.023; Ni and Co, none; S, 0.128; Sb (by difference), 98.856. Japanese: Pb, 0.443; Sn, 0.175; As, 0.008; Cu, 0.034; Fe, 0.015; Zn, tr. Japanese: Pb, 0.424; Sn, 0.012; As, 0.095; Bi, none; Cu, 0.043; Cd, none; Fe, 0.007; Zn, 0.023; Ni and Co, none; S, 0.201; Sb, 99.195. Chinese: Pb, 0.018, Sn, 0.035; As, 0.017, Cu, 0.008; Fe, 0.007; Zn, tr. Chinese: Pb, 0.029; Sn, none; As, 0.090; Cd, none; Fe, 0.004; Zn, 0.027; Ni and Co, tr.; S, 0.078; Sb, 99.760.

Bismuth (American): Pb, Au, Cu, Sb, Te, traces; Ag, 1.37 oz. per ton; Fe, 0.009 per cent.

Copper (electrolytic): Cu, 99.89; Bi, none; Ni, 0.0100; As, 0.00108; Sb, 0.00515 per cent.; Ag, 0.96 oz. per ton. The presence of a small amount of oxygen, less than 0.06 per cent., seems to affect the copper beneficially, and in most of the electrolytic copper, which carries from 99.89 to 99.94 per cent. Cu, oxygen forms by far the largest part of the balance.[2]

Iron-pure is defined by the American Society for Testing Materials (Atlantic City meeting, 1915) as containing under 0.02 per cent. C; 0.03 per cent. Mn; 0.03 per cent. S; 0.01 per cent. P; 0.03 per cent. Cu.

Lead (electrolytic): Ag, 0.29 oz. per ton; Bi, 0.0024 per cent.; Cu, 0.0010; As, tr.; Sb, 0.0066; Fe, 0.0028.

Lead (PARKES process), American: Bi, 0.066–0.110; Sb, 0.0028–0.0076; As, 0.00025–0.009 per cent.[3]

Nickel: Ni, 99.8+; Fe, 0.04; Si, 0.01.

Tin.—(Pulo Brani, 1892, after HENRY LOUIS): Sn, 99.76; Sb, 0.07; Pb, 0.02; Fe, 0.14 per cent.; Cu, As, none. English: Sn, 99.73; Fe, 0.13; Pb, –; Cu, tr. The presence of over 0.8 per cent. of copper spoils tin for tin-pot work, according to my own experience, yet LOUIS gives as a typical English tin analysis: Sn, 98.64; Fe, tr; Pb, 0.20; Cu, 1.16 per cent.

Zinc.—The impurities found in zinc may amount to 2 per cent. of its weight. They are: Pb, Fe, Cd, Cu, C, Si, As, Sb, S, Sn, Ag, Tl, In and Ga. Tin has been found in New Jersey metal. A moderate tenor in Pb makes zinc ductile and malleable, but over 1.5 per cent. Pb renders it tender. Zinc for the brass trade should not carry over 0.05 per cent. Fe. Cd is objectionable if the zinc is to be used for zinc white. Copper and tin

[1] *Min. and Sci. Press*, July 10, 1915.
[2] See also pp. 551 and 553.
[3] See also p. 538.

both render the zinc hard and brittle. Arsenic renders spelter brittle and hard to melt. It is also objectionable in zinc which is to be used for generating hydrogen or in cyanide precipitation, owing to the danger of poisoning workmen with arseniuretted hydrogen.

Roasting

DETAILS OF MONTANA ROASTING-FURNACES

	Tons roasted in 24 hr.	Horsepower required	% sulphur in concentrates	% sulphur in calcines	Area of hearths, sq. ft.	Concentrates per sq. ft. of hearth, lb.	Lb. of coal per ton of concentrates	Cost of roasting per ton
Hand reverberatory, 69½ ft. × 16 ft.	13	.....	35	7–8	1112	12	307.0	$2.00
Allen-O'Hara, two hearths, 94 ft. 0 × 9 ft.	51	3.64	35	8	1692	77	145.0	0.78
Brückner cylinder, 8 ft. × 16 ft.	18–20	1.5	37	9.5	....	......	540.0[1]	1.25
Pearce, single deck	14[3]	1.5	32	7–8	505	55	400.0	0.98[2]
Pearce, double deck, 6-ft. hearths	30[3]	3.0	35	6–7	1010	59	400.0	0.98[2]
Pearce, double deck, 7-ft. hearths	42[3]	3.0	35	6–7	1218	69	182.0	0.98[2]
Keller-Galord-Cole, two sets of six hearths	50	1¾	38	7–10	2592	38	67.0	......
Wethey, two sets of four hearths, 50 ft. × 5 ft.	60	4.0	40	8	2000	60	110.0	......
Wethey, two sets of four hearths, 65 ft. × 10 ft.	90	4.0	35	5–6	2600	70	80.0	......
Herreshoff, five hearths	5–6	.....	35	6	135	80	......	0.40
MacDougall-Evans-Klepetko, six hearths	40	1.667	35	7	952	84	......	0.35
Pearce multiple, six hearths	56[3]	12	35	6–7	2947	38	28.5	0.98[2]

Lead Ores.—It may safely be said that there is no apparatus able to compete with the DWIGHT-LLOYD and HUNTINGTON-HEBERLEIN installations in dead-roasting lead ores. Consequently, discussion of the older types, the BRÜCKNER cylinders,

[1] Data obtained from operations of six months at Great Falls.
[2] Average.
[3] These low figures are due to the character of the ore (Gagnon Mine) which carries from 8 to 12 per cent. of zinc. The table is by HOFMAN.

BROWN-O'HARA, ROPP, etc., would serve no useful purpose. However, a comparison of HUNTINGTON-HEBERLEIN pots and DWIGHT-LLOYD roasters, made at a works where both are used, is of the utmost interest.

Such a comparison was made by W. W. NORTON, regarding the plant at Murray, Utah, at the Salt Lake meeting of the A. I. M. E., August, 1914.

Sulphur Limits of Roasting Equipments

At the Murray plant, modern roasting practice is fully exemplified and there are now in successful operation roasting furnaces or devices of several sorts; namely, GODFREY revolving-hearth furnaces, WEDGE multiple-hearth mechanical roasters, DWIGHT-LLOYD sintering machines, and HUNTINGTON-HEBERLEIN pots. GODFREY and WEDGE furnaces will properly handle material high in sulphur, say ores with 25, 30 and 35 per cent. of that element; D. & L. machines and H. & H. pots will positively not treat efficiently ores or mixtures containing anywhere near the sulphur content mentioned, but are confined to charges containing from 15 to 18 per cent. In passing, it may also be explained that, so far as the knowledge of the writer goes, GODFREY and WEDGE furnaces do not economically eliminate sulphur to an extent sufficiently low for lead-smelting practice. With these simple facts in mind, it will be perfectly clear to all that the metallurgist in charge may elect to treat sulphide ores in either of two ways: He may preroast in GODFREY and WEDGE furnaces and subject the partly roasted product to a final treatment on D. & L. machines and H. & H. pots, or he may dilute the average sulphur in the raw ore to 15 or 18 per cent. by means of an admixture of the requisite quantity of non-sulphur fines and send the mixture thus obtained to D. & L. and H. & H. machines. The Murray plant does both. A certain flexibility is thus afforded for a segregation of the various classes of sulphide ores; moreover, in the matter of oxide fines, one can limit screening operations to a point deemed best metallurgically.

GODFREY and WEDGE furnaces are essentially preroasters; D. & L. machines and H. & H. pots are final roasters. At Murray all final roast is either D. & L. or H. & H.

Cost of Installation

The Murray plant is equipped with two D. & L. machines, the total daily capacity of which may be stated at 220 tons, and 23 H. & H. pots, with capacity of 400 tons. It would, of course, be manifestly unfair to compare directly the total costs of these two installations, but it seems quite safe to say that for almost any given tonnage capacity a D. & L. plant can be built for considerably less than an H. & H. plant, it being understood that by H. & H. is meant the converting-pot portion of an installation only, with no reference to GODFREY furnaces. In the case of the H. & H. one must have heavy cast-iron pots for handling ore in comparatively large units, expensive overhead

handling crane, substantial cooling floor, and, finally, a crusher which the D. & L. does not require. The cost of the installation item must be put down in favor of the D. & L. plant.

Cost of Roasting

Any discussion of roasting costs should, of course, be based on units of sulphur eliminated. In a general way, our experience has shown that the D. & L. will reduce an initial sulphur of about 15 or 16 per cent. to about 4 per cent. in the roasted product, while the H. & H. is capable of handling a slightly higher initial sulphur, say 17 or 18 per cent. with resultant 5 per cent. in product. During a recent period of 47 consecutive days, it is known that units of sulphur eliminated per ton of charge at the D. & L. practically equaled units of sulphur eliminated per ton of H. & H., and it is probable that an exhaustive examination of Murray plant roasting records would show about the same amount of sulphur per ton of charge driven off as between the two sorts of roasters now under review. It follows that figures representing costs of roasting are truly comparable.

The limitations of this paper will not permit of a detailed review of roasting costs, but it may be stated that during the entire year 1913 the H. & H. made the better showing to the extent of about 5 cts. per ton roasted, and for the first 3 months of 1914 the H. & H. also had an advantage of about 3 cts. per ton. Murray experience, everything considered, indicates slightly lower costs for H. & H., as compared with D. & L., but the fact that all calculations are based on operations at an H. & H. plant having twice the capacity of the D. & L. plant must not be overlooked.

Wide Range of Charge

Any intelligent discussion of analysis of raw charge to roasters should have the fundamental thought in mind that the metallurgist must treat what comes to the plant. He cannot always be favored with the proportions of silica, iron and lead which would give the best results, consequently the adaptability of any given roasting device to a variety of materials will be accepted as an item of far-reaching importance.

Two or three years ago, in connection with a visit to three or four custom lead-smelting works newly equipped with D. & L. machines, the writer was somewhat impressed with the limitations placed on the charge the machines were capable of handling. Inquiry brought forth the information that certain sorts of materials could be attempted only by resort to a special layer of fine limestone or other infusible material carried next to the grates; any percentage of raw matte at all seemed out of the question; zinc was naturally "side-stepped" as highly deleterious; much stress was placed upon the proportion of silica to the iron, and nearly all the enthusiasts demanded a goodly percentage of lead provided a choice quality of sinter was to be in evidence. Of late, however, the staff at Murray have found that a wide range of mixtures may be efficiently handled over

he D. & L., and have no doubt that equally good progress has een accomplished at other works. Preroasted ore, any kind of aw sulphide ore or concentrates, flue dust, preroasted matte, or ven raw matte may be combined in certain proportions and uccessfully sintered over these machines. A sufficient quantity f non-sulphur diluent to bring the average of the mixture down o 16 per cent. sulphur must always be added and, of course, the letails of operation must be cared for. However, equally satisactory results have been attained with H. & H. pots.

Turning now to physical character of the raw ore, it is, of ourse, recognized that the air currents are required to permeate thin layer of charge in case of D. & L. treatment, whereas he pot roasters are committed to a much thicker layer; but a hysically fine charge will restrict tonnage on D. & L. just as urely as it will in H. & H. pots, although the D. & L. process is ble to treat slimes or rather fine material which it would be vholly useless to attempt to treat in the H. & H. By way of umming up, it may be stated that the D. & L. process possesses slight advantage over the H. & H. in the matter of flexibility r range of charge, because the D. & L. permits more delicate pplication of operating details which are essential to success; lso extremely fine materials find no proper place in the H. & H. harge.

Lead Losses

We have certain data at hand showing a moderate lead loss n D. & L. machines, these data being based on standard operatng conditions during which the resultant gases and fumes were ampled and analyzed. No data available covering losses with I. & H. pots. The expense and difficulties in connection with ccurately sampling an H. & H. output of 400 tons per day need ot be pointed out and gas measurements and samples taken rom the combined gases of 23 pots on two different main lues might eventuate in metal-recovery data not wholly lependable. . . . It is regarded as doubtful if the D. & . process is productive of any lower metal losses than is the I. & H. process.

Physical Condition of Product

Final-roasting treatment results in a sintered or agglomerated roduct, and material of a desirable physical character is passed long to the blast furnaces. The D. & L. sinter is usually of a orous or cellular structure; the H. & H. tends to greater density r firmness. Published and unpublished opinions of metalurgists have sought to show that the peculiarly open or cokeike structure of the D. & L. sinter carried with it certain extrardinarily favorable properties when subjected to the smelting rocess in the blast furnace, and have even claimed appreciable aving in the coke percentage used for smelting. Rather xaggerated ideas concerning the efficiency of an exposure of orous surfaces to contact with reducing gases have been adanced and intimate mixtures (possibly intimately combined

silica and lead) have been proclaimed as "predigested," and therefore more easily reduced. The writer believes that a partly fused or "predigested" combination may tend to poor results rather than to good results when smelted, for the reason that such substances fuse at too low a temperature in the furnace. Certain writers havegone sofar as to examine the cell structures of the D. & L. product microscopically and have declared that glazed or unglazed surfaces have a bearing upon the readiness with which the products were later reduced in furnaces.

With all due respect to the theories above set forth, it was considered that more dependable conclusions could be drawn by means of actual operating tests and accordingly the MURRAY furnaces during 5 days of August, 1912, were run on two charges, the one containing no D. & L. roast at all, the other containing a rather large amount of this material. It was believed that any peculiar virtue existing in D. & L. product would have abundant opportunity to make itself manifest. The exact charges used are given above, together with the average lead in resultant slag and matte.

TEST CHARGES WITH AND WITHOUT D. & L. SINTER

	Furnaces 1, 3, 7 and 8 (No D. & L.)	Furnace 5 (D. & L.)
Coke, 920 (11½ per cent.)	....	....
Bed 36, bin 7	2970	320
H. & H. roast	2000	....
D. & L. roast	....	4800
Hand-roasted matte	600	400
Iron ore	690	540
Limestone	1640	1840
Scrap iron	100	100
Total	8000	8000
	Per cent.	Per cent.
Average lead in slag for the run	0.63	0.91
Average lead in matte for the run	10.7	14.96

Great pains were used to make the experimental run one of value. The D. & L. roasted product was of a typically honey-combed character. No. 5 furnace was in excellent condition, its operations were closely watched by the metallurgist in charge of the furnaces and by the writer, yet absolutely no strengthening of reduction appeared. On the contrary, No. 5 did worse than the other furnaces.

General blast-furnace experience covering a wide range of charges and a considerable period of time indicates that no particular effect, either good or bad, can be claimed for D. & L. sinter as relating to strength of reduction during the smelting process, and exactly the same remark will apply to H. & H. agglomerated material. (Of course, the D. & L. sintered cakes must be broken to the proper size and the H. & H. material must be crushed suitably small, or distinctly bad reduction will

That both of these products of modern roasting ıment help the speed of furnaces enormously is certainly The final roasters of modern smelters, in supplanting hand roasters and fine-ore-producing mechanical fur- have very naturally served to increase blast-furnace ɜs to a remarkable extent.

ı which product is the better physically, that is to say, will produce the heavier tonnage at blast furnaces, a ss D. & L. sinter does not excel a first-class H. & H. erated product. Moreover, given an inferior quality of ; would seem that the admittedly cellular or at times D. & L. can hardly equal the more firm and stable H. & H. gain, however, real experience at blast furnaces may ;h mere conjecture or theorizing, so the following data mitted with the idea of showing that in this instance at e physical character of the D. & L. produced no better ɜ at blast furnaces than did the physical character of the .. On Aug. 12 and 13, 1912, the following two charges ıelted side by side with the same coke percentage, the ast pressure and as near like conditions in other respects ıs possible to obtain:

	Furnaces 1, 3 and 5 (H. & H.)	Furnaces 7 and 8 (D. & L.)
0 (11½ per cent.)	....	....
ɔin 4	1400	2060
:oast	3000	....
oast	....	3000
ısted matte	400	400
......	1140	580
e	1960	1860
n	100	100
	8000	8000
tons per furnace per day	294	287
	Per cent.	Per cent
lead in slag	0.81	1.03
lead in matte	13.47	13.0

Conclusions

ɔelieved that a fair summary of the actual experience set this paper would be as follows:

	Advantage in favor of
installation	D. & L.
roasting	H. & H.
ɔility of charge	D. & L.
ɔsses	Doubtful
l condition of product	H. & H.

ırticle is unable to point out any overwhelming advantage D. & L. over the H. & H. system, although continued ɜ may upset the balance at any time. If history repeats

itself some new roasting system will take rank over both within a few years.

Copper Roasting.—The cement kiln and DWIGHT-LLOYD are both being used on flotation concentrates, which apparently are the most troublesome item with which the roaster has to deal. The WEDGE, HERRESHOFF and McDOUGAL furnaces are being used on larger material. What any one of them will do on an unknown ore seems to be mainly a matter of experiment.

The table on p. 488 gives some working data.

Lead Roasting Furnace Dimensions[1]

LONG-BEDDED HAND-ROASTING FURNACE WITH LEVEL HEARTH

	I	II	III
Length of hearth	60′	66′	75′
Width of hearth	14′	16′	14′
Hearth area, sq. ft.	840	1056	1150
Length of grate	8′	7′ 9″	8′
Width of grate	3′ 4″	2′ 6″	3′ 6″
Grate area, sq. ft.	14.6[2]	19.4	28
Ratio hearth to grate area	57.5:1	54.5:1	41:1
Space above fire bridge, length and width	7′9″×2′ 2″	7′ 9″×2′ 2″	2′ 6″×1′
Space above flue bridge, length width	No flue bridge	4′ 2″×8″	No flue bridge
Height of fire bridge above hearth	14″	12″	20″
Height of roof above fire bridge	18″	20″	12″
Height of flue bridge above hearth	....	6″	....
Height of roof above flue bridge	....	15″	....
Depth of grate below top of bridge	14″	15″	17″
Character of ore	⅓ galena ⅔ pyrite	Matte Concentration	Pyritic Galena
Depth of charge near flue bridge	3–4″	....	5″
Time ore remains in furnace, hr.	32	24	24
Tons of raw ore per 24 hr.	8.1	12	9
Lb. ore roasted sq. ft. of hearth area	20	21.8	15.65
Character of roasted ore	Partly sintered	Pulverulent	Partly sintered
Per cent. S in roasted ore	12	2–5	3

Brick used. Clay brick inside, red brick or second-class clay brick. Average thickness of side walls. 18 to 30 in. Thickness of roof, 9–15 in.

Roasting Table[3]

1 kg. FeS becomes 0.909 kg. Fe_2O_3
1 kg. FeS_2 becomes 0.667 kg. Fe_2O_3
1 kg. PbS becomes 1.268 kg. $PbSO_4$
1 kg. $CaCO_3$ becomes 0.560 kg. CaO
1 kg. $MgCO_3$ becomes 0.476 kg. MgO

[1] "Metallurgy of Lead," H. O. HOFMAN.
[2] Not clear how this figure is obtained.
[3] INGALLS, "Metallurgy of Zinc."

LENGTH OF TIME CONSUMED IN BURNING HEAPS OF VARIOUS HEIGHTS[1]

Height in feet	Quality of ore	Sample number	Per cent. sulphur	Per cent. copper	Days burning
5	Pyrite..................	1	39	6½	54
5	Chalcopyrite.............	2	18	14.3	41
5	Bornite and pyrite.......	3	31	21.4	53
5½	....	1	39	6.5	66
5½	....	2	18	14.3	50
5½	....	3	31	21.4	65
6	....	1	39	6.5	72
6	....	2	18	14.3	61
6	....	3	31	21.4	74
7	....	1	39	6.5	94
7	....	3	31	21.4	86
7½	Copper glance and pyrite in quartz..............	4	20	23.4	54

IGNITION AND INCANDESCENCE TEMPERATURES, DEG. C., OF SOME METALLIC SULPHIDES, HEATED IN AIR[2]

Material	Size of grain	First notice of SO_2	Incandescence
	I	325	....
Pyrite..............................	II	405	533
	III	472	....
	I	430	....
Pyrrhotite..........................	II	525	595
	III	590	....
Nickel sulphide,....................	I	700	....
Ni, 73.3	II	802	....
S, 26.7	III	886	....
Cobalt sulphide.....................	I	574	....
Co, 66.37	II	684	....
S, 33.63	III	859	....
Cobalt sulphide.....................	I	514	....
Co, 70.20	II	751	850
S, 29.80	III	1019	....
Stibnite............................	I	200	....
	III	340	....
Molybdenite.........................	I	240	....
	III	508	....
Cinnabar............................	I	338	....
	III	420	....
Chalcocite..........................	I	430	....
	III	679	....
Bismuth sulphide....................	I	500	....
Bi, 83.3	III	626	....
Manganese sulphide,.................	I	355	....
Mn, 61.01, Fe, 2.02, S, 33.98	III	700	....
Argentite...........................	I	605	....
	III	875	....
Blende..............................	I	647	....
	III	810	....
Galena (*a*)........................	I	573	....
	III	616	....
Millerite...........................	I	573	....
	III	616	....

[1] PETERS, "Modern Copper Smelting."
[2] HOFMAN, "General Metallurgy," p. 404.
I = 0.1 mm.
II = 0.1 to 0.2 mm.
III = over 0.2 mm.
(*a*) In oxygen.

Dissociation Temperatures of Certain Earths and Salts

The following dissociation temperatures were obtained by W. HEMPEL and C. SCHUBERT, and were determined by heating in an electric oven and determining the end points by the evolved gas volumes. The temperatures were determined with a LE CHATELIER pyrometer. (See also p. 291.)

Material	Beginning of decomposition	End of decomposition
Brown iron ore	470–500°C.	1280°C.
Hematite	1250	1500
Lead peroxide	290	640
Potassium permanganate	160	1400
Potassium bichromate	600	1150
Lead chromate	500	1500
Potassium nitrate	400	950
Sodium nitrate	380	725
Spathic iron ore	470	880
Strontianite	1075	1340
Magnesite	350	900
Blende	150–175	360
Pyrite	480	over 1400
Copper sulphide	220	550
Arsenical pyrites	220	....
Copper pyrites	....	720°

EFFICIENCY OF ROASTING APPARATUS[1]

Apparatus	Lb. ore treated in 24 hr. per sq. ft. of hearth area	Character of product for blast-furnace smelting
I. Roast heaps and stalls	5–20	Good.
II. Reverberatory roasters:		
1. Hand furnaces	24–35	Fair.
2. Mechanical furnaces.		
Average conditions	33–75	Too fine.
Special conditions	150	Too fine.
3. Revolving cylinders	128	Too fine.
III. Blast-roasting pots, range	500–900	Excellent.
Blast-roasting pots, excellent	600	Excellent.
IV. Blast-roasting, thin layers: Dwight-Lloyd system		
1. Intermittent down-draft pans	1000–2000	Excellent.
2. Continuous sintering machines	2200–3000	Excellent.

[1] HOFMAN, "General Metallurgy," p. 433.

Metallurgical Slags

In metallurgy, slagging is the formation, at elevated tem-eratures, of any fluid or semi-fluid mass, with the separation :om it of a metal or metalloidal residue. Slags may be waste roducts, as in lead, iron or copper smelting in the blast furnace, r they may be extremely rich products which must be re-reated, as the slags from copper-refining furnaces or from limes smelting.

The ordinary constituents of the metallurgist's slags may be rouped as follows:

Bases: FeO, CaO, Cu_2O, PbO, MnO, ZnO, MgO, BaO, K_2O, Ja$_2$O, Al_2O_3 (sometimes).

Protecting agents: S, As, Sb, Te, Se.

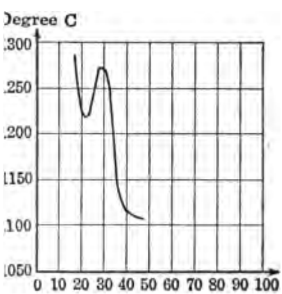
Reducing agents: C, S.

Acids: SiO_2, Al_2O_3 (sometimes).

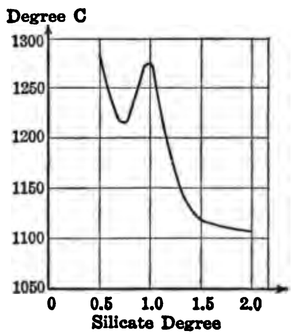
Neutral solvents: CaF_2, Na_2CO_3, K_2CO_3, $CaCl_2$, borates.

Slag Degree.—The metallurgist names his slag by the rela-.ve amounts of oxygen combined with acid and base. Thus bisilicate slag is $FeO{\cdot}SiO_2$, since there is twice the oxygen ombined with the silica as with the iron. It follows, then, 1at the bisilicate of the metallurgist is the silicate of the hemist. A metallurgical monosilicate is $(FeO)_2{\cdot}SiO_2$; a sesqui-.licate $(FeO)_4{\cdot}(SiO_2)_3$.

Iron.—Within reasonable limits, the larger the amount of ·on the more fusible the slag. Slags rich in iron are dangerous 1 a lead furnace, as high iron seems to promote the formation of



ormation temperatures of ferrous silicates. (HOFMAN.)

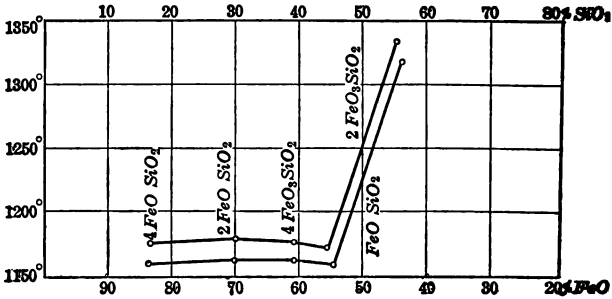


Formation temperatures of ferrous silicates. (HOFMAN.)

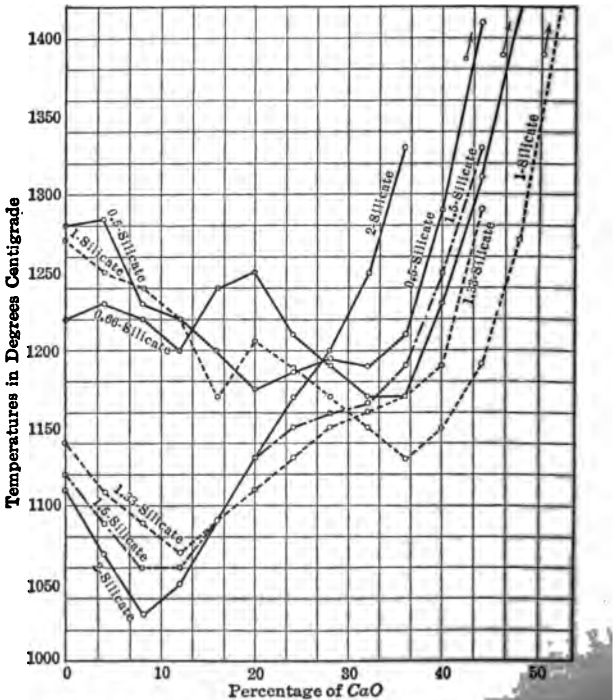
rusts. But high iron is considered a necessity, by some, when inc is present, as it is said high iron promotes the solution f ZnO.

Pyrite—loses one atom of sulphur and enters the matte to he extent of 70 per cent. or over, except in pyritic smelting.

Manganese.—In general its effects are similar to iron, but it

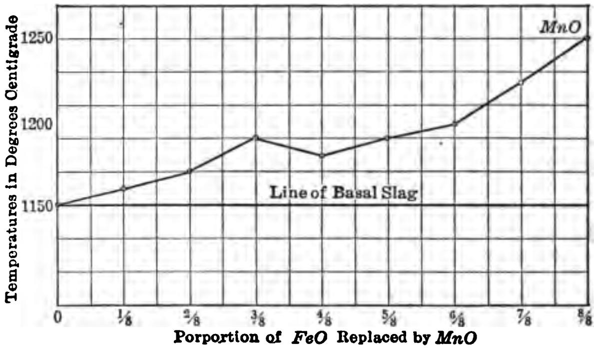


Formation temperatures of ferrous silicates.
Lower line—Sintering temperatures.
Upper line—Temperatures of complete fusion.



Formation temperatures of some ferrous-calcic ... icates.

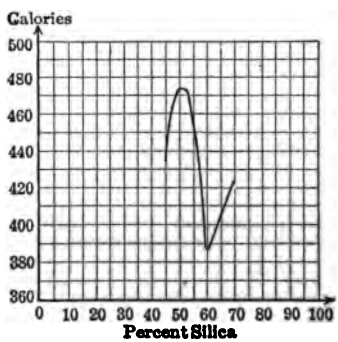
makes a less fusible and more liquid slag than iron. It should be used with as acid slags as are economical. It seems to carry silver into the slag. It reduces the dissolving power of the



Formation temperatures as affected by substitution of MnO for FeO. The slag was a singulo-silicate, SiO_2, 30.1 per cent.; FeO, 35.9 per cent.; CaO, 32 per cent.

slag for zinc oxide, magnesia and barium sulphide. The luster of an Mn slag is usually glassy and small particles are attracted by a magnet.

Lime and Magnesia.—Lime decreases (after a certain point) both the fusibility and the specific gravity of slags. In lead



Total heats of solidification of calcium silicates.

smelting it seems to inhibit the formation of speiss
It is said to enter mattes as CaS. Burnt li
advantage over limestone. Magnesia

siderable extent, but magnesia and zinc are incompatible. The Mg slags usually do not flow well.

Fluorspar—forms extremely fusible slags and will dissolve anything.

Alumina—apparently acts as a base if much silica is present, as an acid if the silica is low, always as a nuisance. In my own work it has seemed to make a most unhappy mixture with high magnesia. Some successful slags with high alumina are given on p. 511. It may be only an accident that they were successful. In iron practice the upper limit of alumina seems to be reached, according to J. E. Johnson, Jr., at about 13–14 per cent. Mr. Menk of the Shenango Furnace Co. has run slags carrying 18–23 per cent. of Al_2O_3, but they were tough and pasty, and coke consumption was high. On the other hand, a slag carrying 10–15 per cent. of Al_2O_3 usually is a better running slag than one carrying only 7. That is, there is a lower danger line as well as an upper.

Barium.—It enters slag as silicate and matte as sulphide, making the former heavy, the latter light, and thereby hindering settling. A barium-iron slag is usually not very fluid, is opaque, steel gray to black, with vitreous luster, and usually is strongly magnetic.

Blende and zinc oxide—cause more difficulty in the blast furnace than anything else. ZnS in the matte lowers its fusibility; ZnO in the slag renders it less fusible. (It goes to slag and matte in about equal proportions.) It carries other metallic sulphides into the slag, and makes furnace accretions. It is most disastrous in combination with magnesia and alumina.

Successful high-zinc slags in lead smelting are said to have been:[1]

Recommended Lead Slags Carrying High Zinc[2]

SiO_2	27.9	30.0	26.0	27.0	24.5	26.0	27.0	26.4
FeO	33.9	29.0	33.4	31.5	29.4	32.1	26.5	22.7
CaO	14.8	14.0	14.4	19.0	24.5	19.0	24.3	24.8
ZnO	16.6	15.5	19.8	15.0	14.5	15.0	14.1	21.0
Total	93.2	88.5	93.6	92.5	92.9	92.1	91.9	94.9

Arsenic, antimony, selenium and tellurium—tend to form speiss; are of more trouble in the subsequent refining than in smelting, except in so far as they volatilize easily and tend to carry off other metals.

Specific Gravities of Slag-forming Compounds[3]

Singulo-silicates of iron, manganese and zinc, about 4.
Bisilicates of iron, manganese and zinc, about 3.5.
The basic silicates of alumina, from 3.2 to 3.4.
The acid silicates of alumina, from 3 to 3.2.

[1] Hofman, "Metallurgy of Lead."
[2] Furman's "Manual of Assaying."
[3] Hofman's "General Metallurgy," p. 74.

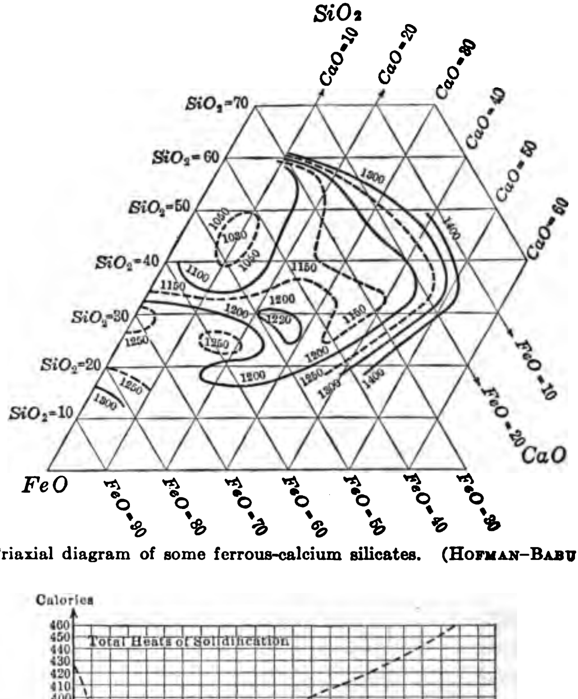
Silicates of magnesia, from 3 to 3.3. Silicates of lime, from 2.6 to 3.

Alkaline silicates, about 2.5. Uncombined silica, 2.6.

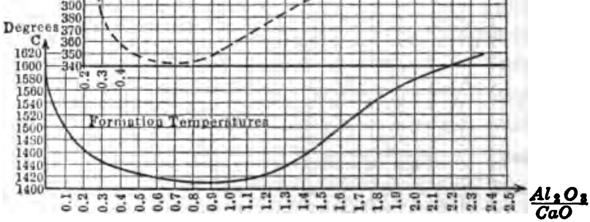
Bisilicate of barium, 4.4. Silicate of lead, 7.

Ferrous sulphide, 4.8. Calcium sulphide, 4.

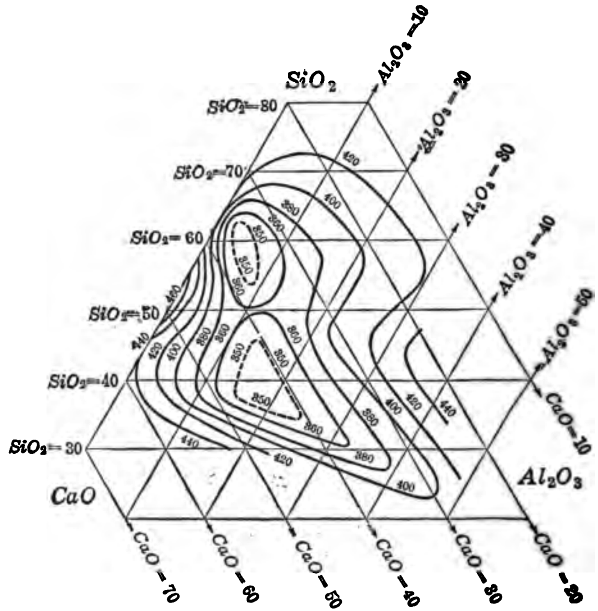
Magnetic oxide, 5. Sulphate of barium, 4.5.



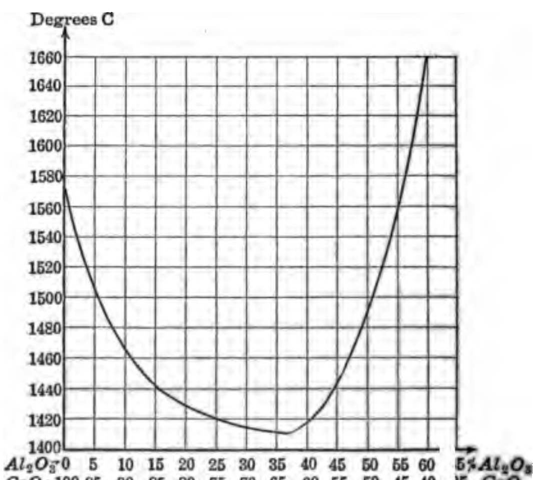
Triaxial diagram of some ferrous-calcium silicates. (HOFMAN–BABU.)



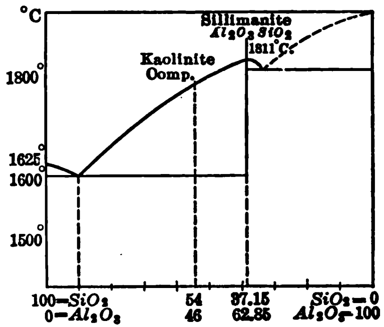
Formation temperatures and total heats of solidification of the calcium-aluminum singulo-silicates.



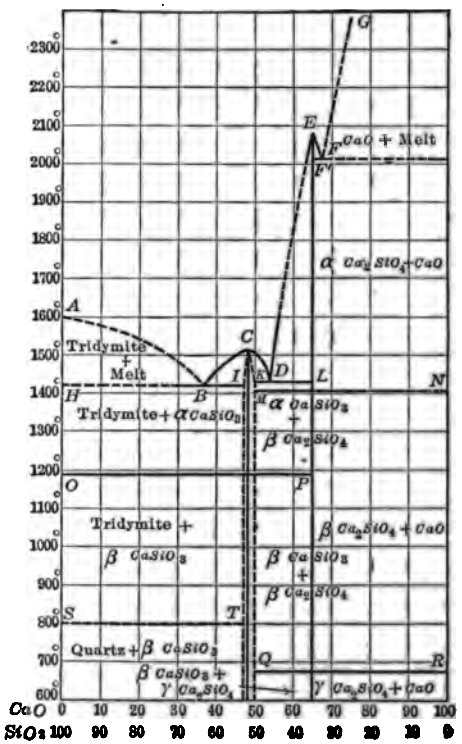
Triaxial diagram of total heats of solidification of calcium-aluminum silicates.



Formation temperatures of the calcium-aluminum singulo-silicates.



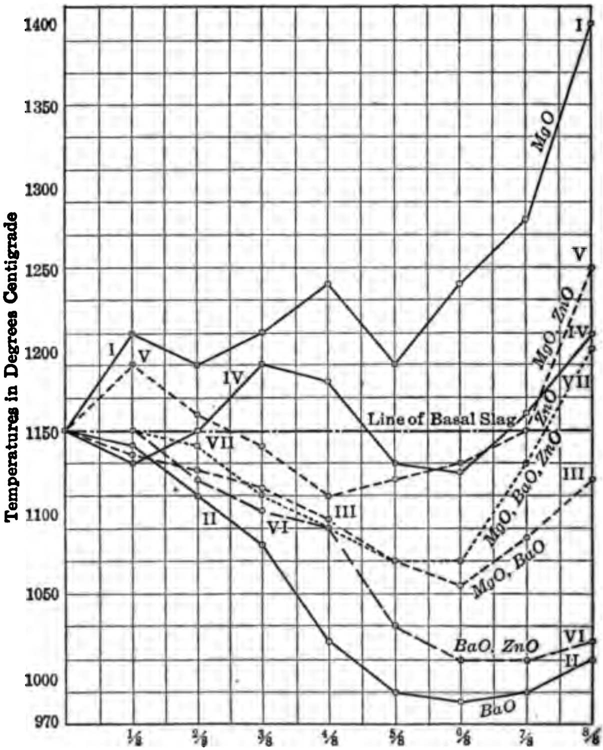
Formation temperatures, Al_2O_3-SiO_2 series.
(After SHEPHERD and RANKINE.)



Freezing temperatures, CaO-SiO_2 series.
(After SHEPHERD and DAY.)

Matte Smelting[1]

In order of decreasing affinity for sulphur[2] the chief metals stand thus according to
FOURNET: Cu, Fe, CoNi, Sn, Zn, Pb, Ag, Hg, Au, As, Sb.[2]
SHÜTZ: Mn, Cu, Ni, Fe, Sn, Zn, Pb.[1]



Formation temperatures as affected by replacement of CaO by MgO, BaO, ZnO.

The slag was a singulo-silicate, SiO_2, 30.1 per cent.; FeO, 35.9 per cent. CaO, 32 per cent.

[1] HOFMAN's "General Metallurgy," p. 74.

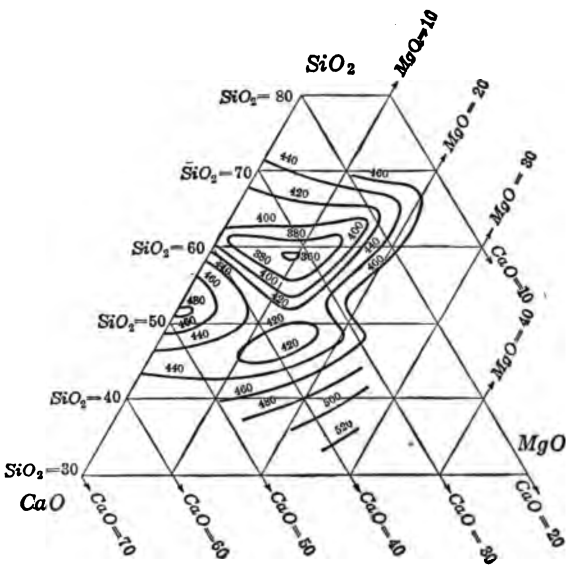
[2] But in a wet way SCHÜRMANN places the sulphides in the following order as regards the rate at which they are decomposed by the nitrates, sulphates and chlorides of other metals: Pd, Hg, Ag, Cu, Bi, Cd, Sb, Sn, Pb, Zn, Ni, Co, Fe, As, Tl, Mn. Thus PdS is not decomposed by the salts of any of the other metals, while $PdCl_2$ converts the sulphides of the other metals into chlorides. With MnS, this is decomposed by salts of any of the other metals, while $MnSO_4$ has no decomposing effect.

Specific Gravities of Matte-forming Compounds[1]

Substances having a specific gravity not greater than 4.7: the sulphides of zinc, molybdenum, calcium and manganese.

Substances having a specific gravity between 4.7 and 5.5: the sulphides of barium, iron, cadmium, nickel, cobalt, and copper; and the magnetic oxide of iron.

Substances with specific gravities from 6 to 9: the sulphides of silver, lead and bismuth; the arsenides and antimonides; and



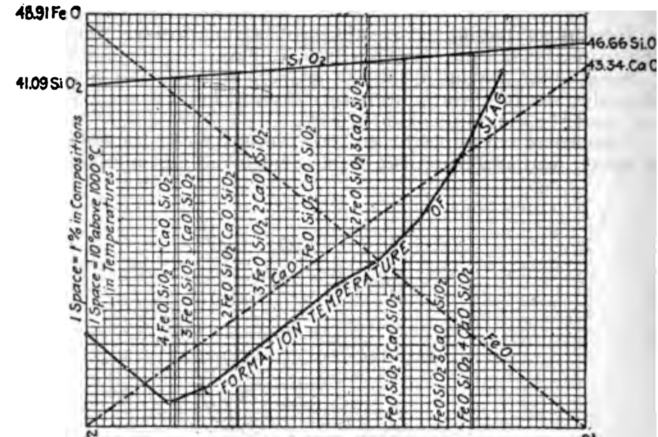
Triaxial diagram, heats of solidification of the calcium-magnesium silicates.

the sulpharsenides and sulphantimonides of silver, copper, bismuth, lead, iron, cobalt and nickel; and metallic lead, iron and copper.

Formation-Temperature Charts

In the illustrations on pp. 506–509 are plotted certain type mixtures of ferrous-calcium silicates and silicate-aluminates, calculated to a basis of $CaO + FeO + SiO_2 = 90$, together with the formation temperature corresponding to the mixture. To use these, determine the general type to which the slag corresponds, and then find the ordinate corresponding most closely to its composition, and read the formation temperature on the ordinate.

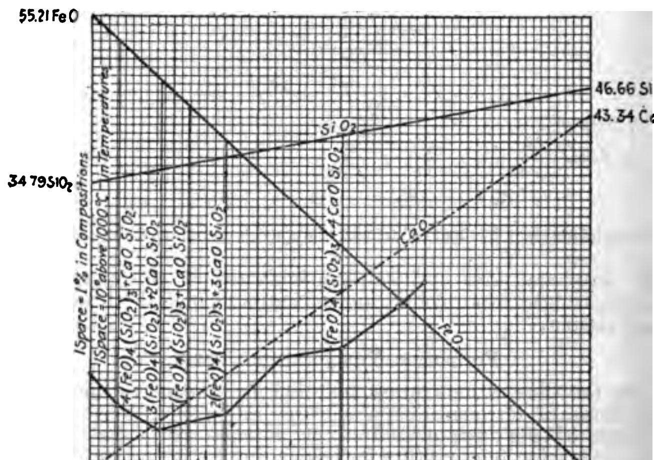
[1] HOFMAN'S "General Metallurgy," p. 74.



SHEET NO. 1

a FeO SiO$_2$ + b CaO SiO$_2$ = 90

Bisilicate Slags

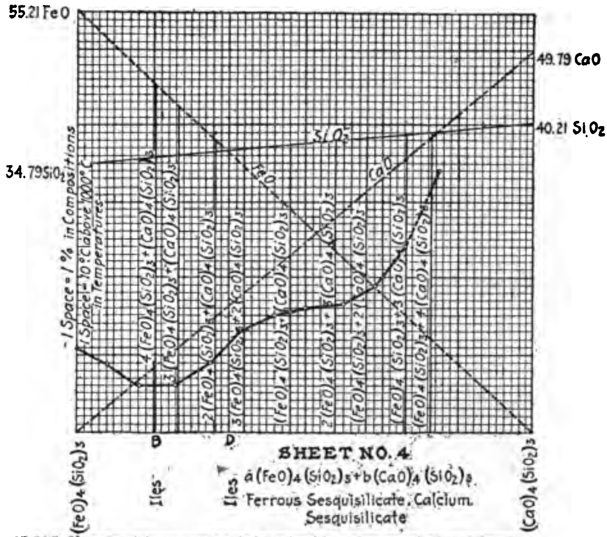


SHEET NO. 2

$a\ (FeO)_4\ (SiO_2)_3 + b\ CaO\ SiO_2$

Ferrous Sesquisilicate, Calcium Bisilicate

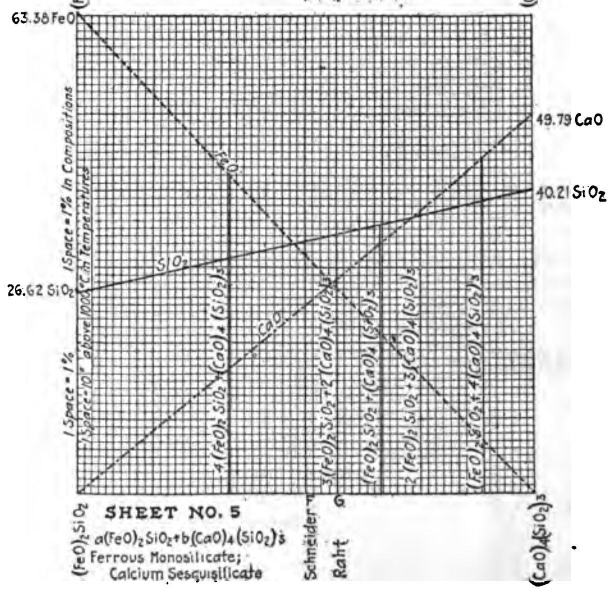
See p. 505 for explanation of these charts.



SHEET NO. 4

$a(FeO)_4(SiO_2)_3 + b(CaO)_4(SiO_2)_3$

Ferrous Sesquisilicate, Calcium Sesquisilicate



SHEET NO. 5

$a(FeO)_2SiO_2 + b(CaO)_4(SiO_2)_3$

Ferrous Monosilicate; Calcium Sesquisilicate

Orthosilicate Slag Factors

Given	Required	To make	Factor	Given	Required	To make	Factor
Al_2O_3	SiO_2	$Al_4(SiO_4)_3$	0.8865	FeS	SiO_2	Fe_2SiO_4	0.3[illegible]
BaO	SiO_2	Ba_2SiO_4	0.1969	FeS_2	SiO_2	Fe_2SiO_4	0.2[illegible]
$BaSO_4$	SiO_2	Ba_2SiO_4	0.1294	K_2O	SiO_2	K_4SiO_4	0.3[illegible]
CaO	SiO_2	Ca_2SiO_4	0.5383	MgO	SiO_2	Mg_2SiO_4	0.74[illegible]
$CaCO_3$	SiO_2	Ca_2SiO_4	0.3017	$MgCO_3$	SiO_2	Mg_2SiO_4	0.3[illegible]
$CaSO_4 \cdot 2H_2O$	SiO_2	Ca_2SiO_4	0.1754	Mn	SiO_2	Mn_2SiO_4	0.5[illegible]
Cu	SiO_2	Cu_4SiO_4	0.2374	MnO	SiO_2	Mn_2SiO_4	0.42[illegible]
CuO	SiO_2	Cu_4SiO_4	0.1897	Na_2O	SiO_2	Na_4SiO_4	0.4[illegible]
Fe	SiO_2	Fe_2SiO_4	0.5403	Pb	SiO_2	Pb_2SiO_4	0.14[illegible]
FeO	SiO_2	Fe_2SiO_4	0.4200	PbO	SiO_2	Pb_2SiO_4	0.13[illegible]
Fe_2O_3	SiO_2	Fe_2SiO_4	0.3780	Zn	SiO_2	Zn_2SiO_4	0.4[illegible]
Fe_3O_4	SiO_2	Fe_2SiO_4	0.3910	ZnO	SiO_2	Zn_2SiO_4	0.37[illegible]

To use the following table for metasilicates, ($M''SiO_3$) halve the amount of basic substance found by the table.

To use it for mesosilicates, $(M''O)_3\,(SiO_2)_2$ decrease by one-quarter the amount found by the table.

SiO_2	Al_2O_3	$Al_4(SiO_4)_3$	1.128	SiO_2	K_2CO_3	K_4SiO_4	4.579
SiO_2	BaO	Ba_2SiO_4	5.080	SiO_2	MgO	Mg_2SiO_4	1.33[illegible]
SiO_2	$BaSO_4$	Ba_2SiO_4	7.730	SiO_2	$MgCO_3$	Mg_2SiO_4	2.79[illegible]
SiO_2	CaO	Ca_2SiO_4	1.858	SiO_2	Mn	Mn_2SiO_4	1.82[illegible]
SiO_2	$CaCO_3$	Ca_2SiO_4	3.315	SiO_2	MnO	Mn_2SiO_4	2.351
SiO_2	$CaSO_4 \cdot 2H_2O$	Ca_2SiO_4	5.702	SiO_2	Na_2CO_3	Na_4SiO_4	3.513
SiO_2	Cu	Cu_2SiO_4	4.212	SiO_2	Pb	Pb_2SiO_4	6.8[illegible]
SiO_2	CuO	Cu_2SiO_4	5.271	SiO_2	PbO	Pb_2SiO_4	7.3[illegible]
SiO_2	Fe	Fe_2SiO_4	1.851	SiO_2	Zn	Zn_2SiO_4	2.16[illegible]
SiO_2	FeO	Fe_2SiO_4	2.381	SiO_2	ZnO	Zn_2SiO_4	2.6[illegible]
SiO_2	Fe_2O_3	Fe_2SiO_4	2.646				
SiO_2	Fe_3O_4	Fe_2SiO_4	2.557				
SiO_2	FeS	Fe_2SiO_4	2.913				
SiO_2	FeS_2	Fe_2SiO_4	3.974				

Sulphides

Given	Required	Factor	Given	Required	Factor
Cu	Cu_2S	1.252	FeS_2	S (total)	0.53[illegible]
Cu	S (to make Cu_2S)	0.2520	FeS_2	FeS ($FeS_2 = FeS + S$)	0.73[illegible]
Cu_2S	Cu	0.7987	Pb	PbS	1.15[illegible]
Cu_2S	S	0.2013	PbS	Pb	0.[illegible]
Fe	FeS	1.574	PbS	Fe ($PbS + Fe = FeS + Pb$)	0.[illegible]
Fe	S (to make FeS)	0.5735			
FeS	Fe	0.6355	S	Cu (to make Cu_2S)	3.9[illegible]
FeS	S	0.3645	S	Cu_2S	4.9[illegible]
FeS	Fe_2O_3	0.9084	S	FeS	2.74[illegible]
			S	Fe_2O_3 (required for FeS)	2.4[illegible]

Alumina Slags (according to Henrich)

	SiO_2	Al_2O_3	FeO	CaO
" slag $(FeO)_4 (CaO)_8 (Al_2O_3)_2 (SiO_2)_3$.	16.05	18.22	25.73	40.00
' slag $(FeO)_6 (CaO)_6 (Al_2O_3)_2 (Si O_2)_6$.	27.15	15.31	32.32	25.22
g $(FeO)_8 (CaO)_4 (Al_2O_3)_2 (SiO_2)_9$.....	35.12	13.21	37.17	14.50

Some Pyritic Slags[1]

Made by	SiO_2	Fe	Al_2O_3	CaO	MgO	Ag	Cu
:. Koch...........	41-45	27-31	5-7	5-15	2-5	....	....
ırpenter..........	33.5	32.26	2.00	11.42	......	.....	...2
utting............	44.0	28.0	1....	18.0	......	0.24	0.27
reeland...........	32.60	38.84	..1.54	8.24	3.44	....	0.35
Heywood.........	31.04	51.40	4.84	6.30	1.37	....	0.4

G's Tables from "Compendium der Metallurgischen Chemie"

›art by weight of .lica requires	Parts by weight of bases	One part by weight of bases requires	Parts by weight of silica
gulo-silicates		For Singulo-silicates	
....	1.86	Lime..............	0.538
›sia..............	1.34	Magnesia..........	0.748
na..............	1.13	Alumina............	0.886
ıs oxide..........	2.38	Ferrous oxide.......	0.420
ınous oxide.....	2.35	Manganous oxide....	0.425
silicates		For Bi-silicates	
....	0.93	Lime..............	1.077
›sia..............	0.67	Magnesia..........	1.497
na..............	0.56	Alumina............	1.773
ıs oxide..........	1.19	Ferrous oxide.......	0.841
ınous oxide.....	1.18	Manganous oxide....	0.851
qui-silicates		For Sesqui-silicates	
....	1.24	Lime..............	0.806
›sia..............	0.89	Magnesia..........	1.122
na..............	0.75	Alumina............	1.330
ıs oxide..........	1.59	Ferrous oxide.......	0.630
ınous oxide.....	1.57	Manganous oxide....	0.688

Rickard's "Pyritic Smelting."

Orthosilicate Slag Factors

Given	Required	To make	Factor	Given	Required	To make	Factor
Al_2O_3	SiO_2	$Al_4(SiO_4)_3$	0.8865	FeS	SiO_2	Fe_2SiO_4	0.3433
BaO	SiO_2	Ba_2SiO_4	0.1969	FeS_2	SiO_2	Fe_2SiO_4	0.2516
$BaSO_4$	SiO_2	Ba_2SiO_4	0.1294	K_2O	SiO_2	K_4SiO_4	0.3203
CaO	SiO_2	Ca_2SiO_4	0.5383	MgO	SiO_2	Mg_2SiO_4	0.7483
$CaCO_3$	SiO_2	Ca_2SiO_4	0.3017	$MgCO_3$	SiO_2	Mg_2SiO_4	0.3580
$CaSO_4 \cdot 2H_2O$	SiO_2	Ca_2SiO_4	0.1754	Mn	SiO_2	Mn_2SiO_4	0.5491
Cu	SiO_2	Cu_4SiO_4	0.2374	MnO	SiO_2	Mn_2SiO_4	0.4254
CuO	SiO_2	Cu_4SiO_4	0.1897	Na_2O	SiO_2	Na_4SiO_4	0.4863
Fe	SiO_2	Fe_2SiO_4	0.5403	Pb	SiO_2	Pb_2SiO_4	0.1460
FeO	SiO_2	Fe_2SiO_4	0.4200	PbO	SiO_2	Pb_2SiO_4	0.1355
Fe_2O_3	SiO_2	Fe_2SiO_4	0.3780	Zn	SiO_2	Zn_2SiO_4	0.4618
Fe_3O_4	SiO_2	Fe_2SiO_4	0.3910	ZnO	SiO_2	Zn_2SiO_4	0.3710

To use the following table for metasilicates, ($M''SiO_3$) halve the amount of basic substance found by the table.

To use it for mesosilicates, $(M''O)_3\,(SiO_2)_2$ decrease by one-quarter the amount found by the table.

SiO_2	Al_2O_3	$Al_4(SiO_4)_3$	1.128	SiO_2	K_2CO_3	K_4SiO_4	4.579
SiO_2	BaO	Ba_2SiO_4	5.080	SiO_2	MgO	Mg_2SiO_4	1.336
SiO_2	$BaSO_4$	Ba_2SiO_4	7.730	SiO_2	$MgCO_3$	Mg_2SiO_4	2.793
SiO_2	CaO	Ca_2SiO_4	1.858	SiO_2	Mn	Mn_2SiO_4	1.821
SiO_2	$CaCO_3$	Ca_2SiO_4	3.315	SiO_2	MnO	Mn_2SiO_4	2.351
SiO_2	$CaSO_4 \cdot 2H_2O$	Ca_2SiO_4	5.702	SiO_2	Na_2CO_3	Na_4SiO_4	3.513
SiO_2	Cu	Cu_2SiO_4	4.212	SiO_2	Pb	Pb_2SiO_4	6.851
SiO_2	CuO	Cu_2SiO_4	5.271	SiO_2	PbO	Pb_2SiO_4	7.381
SiO_2	Fe	Fe_2SiO_4	1.851	SiO_2	Zn	Zn_2SiO_4	2.166
SiO_2	FeO	Fe_2SiO_4	2.381	SiO_2	ZnO	Zn_2SiO_4	2.695
SiO_2	Fe_2O_3	Fe_2SiO_4	2.646				
SiO_2	Fe_2O_4	Fe_2SiO_4	2.557				
SiO_2	FeS	Fe_2SiO_4	2.913				
SiO_2	FeS_2	Fe_2SiO_4	3.974				

Sulphides

Given	Required	Factor	Given	Required	Factor
Cu	Cu_2S	1.252	FeS_2	S (total)	0.5342
Cu	S (to make Cu_2S)	0.2520	FeS_2	FeS ($FeS_2 = FeS + S$)	0.7329
Cu_2S	Cu	0.7987	Pb	PbS	1.155
Cu_2S	S	0.2013	PbS	Pb	0.8658
Fe	FeS	1.574	PbS	Fe ($PbS + Fe = FeS + Pb$)	0.2339
Fe	S (to make FeS)	0.5735			
FeS	Fe	0.6355	S	Cu (to make Cu_2S)	3.968
FeS	S	0.3645	S	Cu_2S	4.968
FeS	Fe_2O_3	0.9084	S	FeS	2.744
			S	Fe_2O_3 (required for FeS)	2.493

Alumina Slags (according to Henrich)

	SiO_2	Al_2O_3	FeO	CaO
"Singulo" slag $(FeO)_4\ (CaO)_8\ (Al_2O_3)_2\ (SiO_2)_8$.	16.05	18.22	25.73	40.00
"Sesqui" slag $(FeO)_6\ (CaO)_6\ (Al_2O_3)_2\ (Si\ O_2)_6$.	27.15	15.31	32.32	25.22
"Bi" slag $(FeO)_8\ (CaO)_4\ (Al_2O_3)_2\ (SiO_2)_8$.....	35.12	13.21	37.17	14.50

Some Pyritic Slags[1]

Made by	SiO_2	Fe	Al_2O_3	CaO	MgO	Ag	Cu
Walter E. Koch...........	41–45	27–31	5–7	5–15	2–5	....	....
F. R. Carpenter..........	33.5	32.26	2.00	11.42	......	....	...2
W. H. Nutting............	44.0	28.0	1....	18.0	......	0.24	0.27
W. H. Freeland...........	32.60	38.84	..1.54	8.24	3.44	....	0.35
Wm. A. Heywood.........	31.04	51.40	4.84	6.30	1.37	....	0.4

Balling's Tables from "Compendium der Metallurgischen Chemie"

One part by weight of silica requires	Parts by weight of bases	One part by weight of bases requires	Parts by weight of silica
For Singulo-silicates		For Singulo-silicates	
Lime................	1.86	Lime..............	0.538
Magnesia............	1.34	Magnesia..........	0.748
Alumina.............	1.13	Alumina...........	0.886
Ferrous oxide.........	2.38	Ferrous oxide......	0.420
Manganous oxide.....	2.35	Manganous oxide....	0.425
For Bi-silicates		For Bi-silicates	
Lime................	0.93	Lime..............	1.077
Magnesia............	0.67	Magnesia..........	1.497
Alumina.............	0.56	Alumina...........	1.773
Ferrous oxide.........	1.19	Ferrous oxide......	0.841
Manganous oxide.....	1.18	Manganous oxide....	0.851
For Sesqui-silicates		For Sesqui-silicates	
Lime................	1.24	Lime..............	0.806
Magnesia............	0.89	Magnesia..........	1.122
Alumina.............	0.75	Alumina...........	1.330
Ferrous oxide.........	1.59	Ferrous oxide......	0.630
Manganous oxide.....	1.57	Manganous oxide....	0.638

[1] T. A. Rickard's "Pyritic Smelting."

Balling's Table for Alumina as Acid

To form $(MO)_3\,Al_2O_3$

1 part Al_2O_3 requires parts of		1 part of base requires parts Al_2O_3	
MgO	1.72	MgO	0.580
CaO	2.47	CaO	0.417
MnO	3.03	MnO	0.330
FeO	3.07	FeO	0.325
ZnO	3.48	ZnO	0.287
BaO	6.56	BaO	0.153
Na_2O	2.65	Na_2O	0.377
K_2O	4.03	K_2O	0.248

I. Auxiliary Tables to Accompany Balling's Slag Table

Formula	Mol. wt.	Log.
$(MgO)_4SiO_2$	221.84	2.34604
$(CaO)_4SiO_2$	284.8	2.45454
$(MnO)_4SiO_2$	344.4	2.53706
$(FeO)_4SiO_2$	348.0	2.54158
$(BaO)_4SiO_2$	674.0	2.82866
$(MgO)_3SiO_2$	181.48	2.25883
$(CaO)_3SiO_2$	228.7	2.35927
$(MnO)_3SiO_2$	273.4	2.43680
$(FeO)_3SiO_2$	276.1	2.44107
$(BaO)_3SiO_2$	520.6	2.71650
$(MgO)_2SiO_2$	141.12	2.14959
$(CaO)_2SiO_2$	172.6	2.23704
$(MnO)_2SiO_2$	202.4	2.30621
$(FeO)_2SiO_2$	204.2	2.31006
$(BaO)_2SiO_2$	367.2	2.56490
$(MgO)_4(SiO_2)_3$	342.64	2.53484
$(CaO)_4(SiO_2)_3$	405.6	2.60810
$(MnO)_4(SiO_2)_3$	465.2	2.66755
$(FeO)_4(SiO_2)_3$	468.8	2.67099
$(BaO)_4(SiO_2)_3$	794.8	2.90026
$MgOSiO_2$	100.76	2.00329
$CaOSiO_2$	116.5	2.06633
$MnOSiO_2$	131.4	2.11860
$FeOSiO_2$	132.3	2.12156
$BaOSiO_2$	213.8	2.33001

II. Ratios of Molecular Weights

$CaSiO_3$	$FeSiO_3$	$Fe_4Si_3O_{10}$	Fe_2SiO_4
1.000	1.136	4.024	1.757
$Ca_4Si_3O_{10}$	$Fe_4Si_3O_{10}$	Fe_2SiO_4	Fe_3SiO_5
1.000	1.156	0.5035	0.6807
Ca_2SiO_4	Fe_2SiO_4	Fe_3SiO_5	Fe_4SiO_6
1.000	1.183	1.600	2.016
$CaSiO_3$	$Ca_4Si_3O_{10}$	Ca_2SiO_4	....
1.000	3.483	1.482	....

$FeSiO_3$	$Fe_4Si_3O_4$	Fe_2SiO_4	Fe_3SiO_5	Fe_4SiO_6
1.00	3.543	1.543	2.087	2.630

III. Bases

Radical	Mol. wt.	Log.
MgO	40.36	1.60595
CaO	56.1	1.74896
Na_2O	62.1	1.79309
MnO	71.0	1.85126
FeO	71.9	1.85673
K_2O	94.3	1.97451
SrO	103.6	2.01536
ZnO	106.6	2.02776
Cu_2O	143.2	2.15594
BaO	153.4	2.18583
PbO	222.7	2.34772

Acids

Radical	Mol. wt.	Log.
Al_2O_3	102.2	2.00945
B_2O_3	70.0	1.84510
P_2O_5	142.0	2.15229
SiO_2	60.4	1.78104
TiO_2	80.1	1.90363

IV. Composition of Type Slags
(Calculated to a 90 per cent. total)

Compound	SiO_2	FeO	CaO
$FeO \cdot SiO_2$	41.1	48.9	....
$4(FeO \cdot SiO_2) + CaO \cdot SiO_2$	42.1	40.1	7.8
$3(FeO \cdot SiO_2) + CaO \cdot SiO_2$	42.4	37.8	9.8
$2(FeO \cdot SiO_2) + CaO \cdot SiO_2$	42.8	34.0	13.2
$3(FeO \cdot SiO_2) + 2(CaO \cdot SiO_2)$	43.2	30.8	16.0
$FeO \cdot SiO_2 + CaO \cdot SiO_2$	43.6	26.1	20.3
$2(FeO \cdot SiO) + 3(CaO \cdot SiO_2)$	44.2	21.1	24.7
$FeO \cdot SiO_2 + 2(CaO \cdot SiO_2)$	44.7	17.7	27.6
$FeO \cdot SiO_2 + 3(CaO \cdot SiO_2)$	45.2	13.4	31.4
$FeO \cdot SiO_2 + 4(CaO \cdot SiO_2)$	45.4	10.8	33.8
$CaO \cdot SiO_2$	46.7	....	43.3
$(FeO)_4(SiO_2)_3$	34.8	55.2	....
$4(FeO)_4(SiO_2)_3 + CaO \cdot SiO_2$	35.5	52.0	2.5
$3(FeO)_4(SiO)_3 + 2CaO \cdot SiO_2$	36.4	47.4	6.2
$(FeO)_4(SiO_2)_3 + CaO \cdot SiO_2$	37.2	44.2	8.6
$2(FeO)_4(SiO_2)_3 + 3CaO \cdot SiO_2$	38.1	40.2	11.7
$(FeO)_4(SiO_2)_3 + 4CaO \cdot SiO_2$	40.9	27.5	21.6
$CaO \cdot SiO_2$	46.7	....	43.3
$(FeO)_2SiO_2$	26.6	63.4	....
$4(FeO)_2SiO_2\ CaO \cdot SiO_2$	29.1	55.5	5.4
$3(FeO)_2SiO_2 + 2CaO \cdot SiO_2$	32.2	45.9	11.9
$(FeO)_2SiO_2 + CaO \cdot SiO_2$	33.9	40.4	15.7
$2(FeO)_2SiO_2 + CaO \cdot SiO_2$	35.8	34.2	20.0
$(FeO)_2SiO_2 + 4CaO \cdot SiO_2$	40.6	19.3	30.1
$CaO \cdot SiO_2$	46.7	....	43.3

	SiO_2	FeO_2	CaO
$(FeO)_2SiO_2$	26.6	63.4	....
$4(FeO)_2SiO_2 + (CaO)_4(SiO_2)_3$	31.1	42.4	16.5
$3(FeO)_2SiO_2 + 2(CaO)_4(SiO_2)_3$	34.3	27.3	28.4
$(FeO)_2SiO_2 + (CaO)_4(SiO_2)_3$	35.7	21.2	33.1
$2(FeO)_2SiO_2 + 3(CaO)_4(SiO_2)_3$	36.8	15.9	37.3
$(FeO)_2SiO_2 + 4(CaO)_4(SiO_2)_3$	38.7	7.1	44.2
$(CaO)_4(SiO_2)_3$	40.2	....	49.8
$(FeO)_2SiO_2$	26.6	63.4	....
$4(FeO)_2SiO_2 + (CaO)_2SiO_2$	27.5	52.3	10.2
$3(FeO)_2SiO_2 + (CaO)_2SiO_2$	27.7	49.4	12.9
$2(FeO)_2SiO_2 + (CaO)_2SiO_2$	28.1	44.5	17.4
$3(FeO)_2SiO_2 + 2(CaO)_2SiO_2$	28.4	40.5	21.1
$(FeO)_2SiO_2 + (CaO)_2SiO_2$	28.9	34.3	26.8
$2(FeO)_2SiO_2 + 3(CaO)_2SiO_2$	29.4	27.9	32.7
$(FeO)_2SiO_2 + 2(CaO)_2SiO_2$	29.6	23.6	36.8
$(FeO)_2SiO_2 + 3(CaO)_2SiO_2$	30.1	17.9	42.0
$(FeO)_2SiO_2 + 4(CaO)_2SiO_2$	30.4	14.4	45.2
$(CaO)_2SiO_2$	31.5	....	58.5

	SiO_2	FeO	CaO
$(FeO)_4(SiO_2)_3$	34.8	55.2	....
$4(FeO)_4(SiO_2)_3 + (CaO)_4(SiO_2)_3$	35.7	45.4	8.9
$3(FeO)_4(SiO_2)_3 + (CaO)_4(SiO_2)_3$	36.0	42.9	11.1
$2(FeO)_4(SiO_2)_3 + (CaO)_4(SiO_2)_3$	36.6	38.4	15.0
$3(FeO)_4(SiO_2)_3 + 2(CaO)_4(SiO_2)_3$	36.7	35.1	18.2
$(FeO)_4(SiO_2)_3 + (CaO)_4(SiO_2)_3$	37.3	29.6	23.1
$2(FeO)_4(SiO_2)_3 + 3(CaO)_4(SiO_2)_3$	37.9	24.0	28.1
$(FeO)_4(SiO_2)_3 + 2(CaO)_4(SiO_2)_3$	38.2	20.2	31.6
$(FeO)_4(SiO_2)_3 + 3(CaO)_4(SiO_2)_3$	38.7	15.4	35.9
$(FeO)_4(SiO_2)_3 + 4(CaO)_4(SiO_2)_3$	39.0	12.4	38.6
$(CaO)_4(SiO_2)_3$	40.2	....	49.8

Formation Temperature of Some Pure Ferrous Silicates

4FeO, SiO_2 = 82.8 % FeO, 17.2 % SiO_2 = 1280°C.[1]
3FeO, $2SiO_2$ = 64.3 % FeO, 35.7 % SiO_2 = 1140°C.[1]
FeO, SiO_2 = 54.55 % FeO, 45.45 % SiO_2 = 1110°C.[1]
2CaO, SiO_2 = 65.0 % CaO, 35.0 % SiO_2 = 1570°C.[2]
CaO, SiO_2 = 48.2 % CaO, 51.8 % SiO_2 = 1540°C.[3]
3CaO, $2SiO_2$ = 58.2 % CaO, 41.8 % SiO_2 = dissociates at 1475°C.[3]
3CaO, SiO_2 = 73.6 % CaO, 26.4 % SiO_2 = dissociates at 1900°, before melting[3]
4CaO, $3SiO_2$ = 37.0 % CaO, 63.0 % SiO_2 = 1436°C.[3]
4CaO, $3SiO_2$ = 54.5 % CaO, 45.5 % SiO_2 = 1455°C.[3]

Formation and Melting Temperatures of Silicates[5]

Description	SiO_2	Al_2O_3	Composition		MgO	BaO	MnO	Formation temp.	Fusing temp.
			FeO	CaO					
Iron slag[4].....	50.0	17.0	3.0	30.0	.....	.....	.....	1392	1208
Iron slag[4].....	43.9	8.6	4.5	31.4	10.2	.....	0.3	1450	1250
Lead slag[4].....	36.0	8.5	40.0	4.0	3.0	7.5	.....	1220	1160
Lead slag[4].....	31.47	......	45.68	22.85	.....	.....	.....	1190	......
Copper slag[4]...	33.0	7.0	60.3	.....	.....	.....	.....	1273	1176
Copper slag[4]...	40.80	......	39.46	19.74	.....	.....	.....	1160	......

[1] *Trans. A. I. M. E.*, Vol. 29.
[2] F. T. Havard,. "Furnaces and Refractories."
[3] Rankin and Wright, *Am. Journ. Sci.*, January, 1915.
[4] From Havard, "Furnaces and Refractories."
[5] See also p. 278.

Miscellaneous Furnace Products

	SiO_2	Al_2O_3	CaO	Fe_2O_3	MnO	MgO	CaS	NaKO	P_2O_5	FeO
Iron blast furnace slag[5]	34.48	15.13	32.82	0.76	1.62	7.44	2.22	1.92	0.15	......
Acid open hearth slag[5]	48.19	......	......	......	15.74	0.09	......	......	......	35.98
Basic open hearth slag[5]	12.30	......	49.39	3.56	......	3.42	......	......	14.78	9.10
Bessemer converter slag[5]	47.25	3.45	1.84	......	31.89	......	......	......	......	15.43
Basic converter slag[5]	7.73	3.72	50.76	1.00	2.05	4.00	1.71	......	21.90	4.73
Charcoal iron furnace slag[7]	40.0	16.0	26.0	......	......	14.0	......	4.0	......	......
Arizona converter slag[8]	28.6	8.6	0.6	......	......	......	......	1.5	......	58.8
Arizona converter slag[9]	30.0	6.0	1.3	......	......	......	......	1.6	......	58.5
Arizona converter slag[8]	30.5	16.0	......	......	......	......	......	1.8	......	59 8
Arizona converter slag[8]	21.4	9.6	......	......	......	......	......	2.2	......	68.0

	SiO_2	WO_3	SnO	FeO	MnO	Al_2O_3	CaO	MgO	Na_2O	ZnO	S	Cu	Total
Tin slag (glass), Cornish reverberatory[1]	39.4	1.3	8.1	26.2	Trace	14.8	7.9	0.5	1.7	......	......	......	99.9
Tin slag, French reverberatory[1]	40.0	......	7.5	20.3	11.1	9.6	3.6	1.0	......	......	......	......	93.1
Tin slag, Bohemia, from slag smelting[4]	24.06	24.03	9.36	20.75	5.64	9.00	3.5	0.37	......	......	......	......	......
Tin slag, second slag smelting[4]	27.5	3.0	5.40	48.2	1.5	8.5	3.4	1.6	......	......	......	......	......
Mansfeld copper slag[2] (trisilicate)	57.43	F–2.09	......	7.47	......	7.83	23.40	0.87	......	......	......	0.27	......
Mansfeld copper slag[2]	53.83	......	......	4.35	......	4.43	33.1	1.67	......	......	......	0.20	......
Mansfeld copper slag[3]	46.70	......	......	3.46	0.28	16.63	21.81	4.40	4.05	1.93	0.16	0.24	99.75
Ilsenburg copper slag (sp. gr. = 3.342)[3]	45.05	......	......	41.15	......	7.24	0.65	0.74	......	......	......	1.05	96.23
Oker (subsilicate)[4]	21.62	......	......	65.62	......	5.15	2.57	......	......	......	2.08	2.01	......
Arizona copper practice[6]	35.6	......	......	31.9	......	22.3	9.6	0.7	......	......	......	0.35	

Arizona copper practice[6]	35.4			23.8		13.5	23.0	2.2				0.28	
Arizona copper practice[6]	39.8			30.7		20.0	3.0	2.1				0.35	
Arizona copper practice[6]	40.6			34.7		14.5	7.5					0.38	
Arizona copper practice[6]	43.7			31.1		15.3	6.8	2.2				0.63	
New Jersey cupola practice[6]	28.4			35.5			22.65					0.45	
New Jersey matting furnace[6]	33.43			45.65		5.23	4.00	1.95				0.83[10]	
Arizona converter slag[6]	16.5			63.7								2.50	
Blast-furnace sow[6]	2.14			Fe 7.82								86.98	
Settler sow[6]	2.87			Fe 18.31							22.58	56.81	
Copper converter slag, acid lining, Parrott.[2]	36.80			Fe 50.40		6.80	tr.			4.43	0.47	1.00	99.8
Copper converter slag, acid lining, Anaconda[2]	35.70			Fe 55.83	0.22	1.76				0.86	1.03	2.14	97.54
Nickel slag, ore smelting[11]	38.0	Ni = 0.45		43.0		10.0	4.5	2.5			2.00	0.4	
Nickel sow, ore smelting[11]	2.11	Ni = 4.85	Fe = 88.17								4.05	1.4	
Zinc retort residue[1]	69.72			9.03		10.08	6.17	1.84	3.44	2.40	0.91		
Slag from basic lined refining furnace[2]	26.75		5.7	3.75			1.67	0.51				51.70	
Copper refinery slag	39.02			10.54		4.19	5.04				0.61	35.2	
Lead slag from Freiberg[4]	27.2		PbO	40.0						10.1			
Freiberg, lead slag, roasting and reduction[4]	23.95		2.87	44.41	0.92	4.45	4.75	0.54	P_2O_5	14.81	4.46	0.69	
Przibram, lead slag, roasting and reduction[4]	37.50		0.48	28.37	2.51	7.81	14.70	1.11	2.11	4.07	0.92		
Lead blast furnace, Middle West, U. S. A[3]	30.67		1.10	30.40		15.50	10.95	6.02		1.09		0.22	
Lead Reverberatory, Middle West, U. S. A[3]	41.35		1.00	9.24		27.05	17.50	3.14					

[1] HENRY LOUIS, "Tin." [2] PETERS, "Modern Copper Smelting." [3] Private notes.
[4] SCHNABEL's "Handbook of Metallurgy." [5] RICHARDS' "Metallurgical Calculations."
[6] Private notes. Some of these Arizona slags are interesting because of their high alumina content.
[7] Private notes. A wonderfully clean slag, almost snow white in color.
[8] Poured slag, ore lining. [9] Poured slag, quartz lining. [10] 60 per cent. matte being produced.
[11] This nickel slag, given by SCHNABEL, is far from typical of modern operations. For instance, a year's results in Canadian practice gave the following average for the blast-furnace slag: SiO_2, 35.37; Fe, 34.69; CaO, 5; MgO, 5.10; Al_2O_3, 8; S, 0.82; Cu, 2.4; Ni, 3.9 per cent. The corresponding matte, for a yearly average, carried: Ni, 19.33; Cu, 13.23 per cent. The succeeding year gave: SiO_2, 34.89; Fe, 38.06; S, 1.01; Cu, 2.0; Ni, 3.9; with corresponding matte: Ni, 20.55; Cu, 10.7 per cent. The year following this showed: SiO_2, 33.90; Fe, 39.59; S, 1.31; Cu, 1.8; Ni, 3.9; with corresponding matte: Ni, 20.92, and Cu, 8.57 per cent.

TYPICAL FURNACE PRODUCTS

	Cu	Pb	Fe	Ni	Co	Sb	As	Ag	Au	S	Bi	Zn
Speiss—Schmöllnitz[1]	12.99	0.09	12.63	1.40	0.09	60.00	7.42	0.36	0.06	2.04	1.26	......
Speiss—Neusohl[1]	41.18	0.69	35.41	0.09	0.04	10.79	6.10	0.03	......	2.60	......	......
Black copper—Mansfeld	94.52	1.93	0.62	0.76	0.23	......	......	0.03	......	0.86	......	1.09
Converter copper—Mexican	95.64	1.864	0.068	......	......	0.171	0.085	1.63	0.002	......	None	......
Converter copper—Australian	96.39	0.684	0.0123	......	......	0.364	0.509	0.33	0.041	0.265	0.088	......
Converter copper—Australian	......	0.262	0.116	0.100	......	0.012	tr.	0.30	0.01	0.242	......	......
Converter copper—Western U. S.	99.28	tr.	0.044	0.014	......	0.010	0.016	0.34	0.01	0.005	0.004	......
Lead from blast furnace—Freiberg[1]	0.225	95.088	0.007	......	......	0.958	......	0.47	......	......	0.019	0.002
Lead from Przibram[1]	0.11	97.359	0.003	0.001	......	1.524	......	0.423	......	0.03	0.007	0.001

[1] SCHNABEL, "Handbook of Metallurgy."

Total Heat in Calories per Kg. of Melted Slag
(After Akerman)

Calories	Per cent., SiO_2	Per cent., CaO	Per cent., Al_2O_3	Calories	Per cent., SiO_2	Per cent., CaO	Per cent., Al_2O_3
347	59	36	5	360	31	37	32
	39	42	19		46	37	17
350	63	35	2		58	32	10
	58	35	7	380	58	27	15
	58	37	5		62	37	1
	53	37	10		38	52	10
	41	42	17		25	34	41
	38	47	15		44	33	23
	39	43	19	400	60	20	20
	37	40	23		65	35	0
	66	32	2		41	52	7
	59	38	3		37	53	10
	48	42	10		21	32	47
360	40	48	12		43	30	27
	34	48	18				

Typical Lead Slags[1]

	SiO_2	Fe(Mn)O	Ca(Ba, Mg)O	Total
Eilers	28	50	12	90
Eilers	30	40	20	90
Livingstone	30	36	20	86
Iles	32	33	23	88
Schneider	33	33	24	90
Page	33	36	16	85
Hahn	34	50	12	96
Raht	35	27	28	90
Hahn	36	40	20	96
Murray	40	34	26	100
Hixon	34	33	23	90
Hixon	33.4	34.1	21	88.5
Hixon	30	40	20	90

Temperatures of Metallurgical Operations

Copper blast-furnace smelting:
- Furnace running fast........................ 1260°C.[1]
- Normal smelting.............................. 1215°C.[1]
- Slow smelting, lower limit................... 1130°C.[1]
- Pyritic smelting..................... 1240°–1350°C.[1]

[1] Hofman, "Metallurgy of Lead," and Hixon's "Lead Smelting and Copper Converting."

Copper converters:

Matte introduced	1170°C.
Turned down to skim	1297°C.
Turned back to blow	1284°C.
Cooling during skimming	13°C.
Temperature of escaping gas at end of 10 minutes	1260°C.
Temperature of escaping gas at end of 20 minutes	1270°C.
Temperature of escaping gas at end of 30 minutes	1275°C.
Temperature of escaping gas at finish	1195°C.

Copper-refining furnaces:

Charge melted and ready to rabble	1141°C.
After 25 minutes rabbling	1103°C.
After 75 minutes rabbling	1103°C.
At end of rabbling	1103°C.
After 20 minutes poling	1110°C.
At end of poling	1117°C.
Heated to	1125°C.
After ladling 20 minutes	1121°C.

Lead blast-furnace work:

On two-fifths slag, Fe, 30 per cent.; CaO, 12 per cent.; Al_2O_3, 8 per cent.; SiO_2, 31 per cent., Zn, 10 per cent.; was 1126°C.

On half slag, 1134°C.

On three-fifths slag, Fe, 30.5 – 31 per cent.; CaO, 15 – 14.5 per cent.; Al_2O_3, 6.4 – 6.6 per cent.; SiO_2, 34 – 32 per cent.; Zn, 5.8 per cent.; MgO, 1.3 per cent., MnO, 3.7 – 3.8 per cent., 1170° – 1149°C.

The temperature change seems to be about 9°C. per cent. of silica up or down, from the above figures.

Reverberatory smelting—copper matting:

Slag temperature	1200°–1310°C.[1]
Slag melting point	1190°–1285°C.[1]
Furnace temperatures	1260°–1725°C.[1]

Reverberatory roasting—leady mattes:

1215°C. at fire box to 505°C. at flue end.

Reverberatory smelting flue:

1300°C. at furnace; 1217° at 14 ft. from furnace; 1112° at 27 ft.; 1097° at 41 ft.; 1045° at 54 ft.; 911° at 67 ft.; 807° at 80 ft.; 767° at 94 ft.; 727° at 107 ft.; 642° at 120 ft. (foot of stack).

Iron[2]

	Deg. C.
Blast furnace at tuyères	2000
Blast-furnace tapping	1600
Open-hearth furnace during boil	1500

[1] Rounded averages (to nearest 5°C.) of figures given by G. H. Clevenger, *Metallurgical and Chemical Engineering*, August, 1913. Other figures not averaged.

[2] Stowe-Fuller Co.'s catalog.

Medium-hard steel at tapping	1600
Gas leaving producers	700
Gas leaving regenerators	1200
Air leaving regenerators	1100
Waste gas at stack	300
Medium steel ready to roll	1050
Glass pots working	1050
Glass pots refining	1325
Tanks for casting glass	1325
Crucible-steel furnace	1300
Cement rotary clinkering kiln	1684
Ingot being rolled	1065
Heating furnace	1150

Modern Copper Blast Furnaces[1]

	Dimensions at tuyère, in.	Number and size of tuyères, in.	Center of tuyère to feed floor ft. in.	Height of smelting column, ft.	Blast pressure, oz.	Approximate capacity, tons per day
Anaconda, Mont[2]	56×1044	150–4	19	.....	40	3000
Cananea, Mexico	48×210	36–4¾	10 4½	9	16	280
Garfield, Utah	48×240	....	13 0	10	24	360
Mammoth, Calif	50×180	34–4¾	....	9	42	400
Steptoe, Nev	42×240	48–4	....	....	40	300–500
Cerro de Pasco, Peru	56×180	28–4	....	....	24	300
Mason Valley, Nev	47×300	50–4	12 1	12	42	720
Tezuitlan, Mex	54×240	40–5	14 6	....	28–32	500
Canadian Copper Co.	50×204	....	....	14	.....	400
	50×240	....	....	14	.....	550
Mond Nickel Co	50×240	....	....	12	.....	550
Trail, B. C.	42×210	....	....	8	.....	350
	42×360	....	....	8	.....	650
	42×264	....	....	8	.....	460
	42×420	....	....	8	.....	700
	50×420	....	....	8	.....	875
Grand Forks, B. C.	44×266½	....	....	12	.....	500
	48×260	....	....	12	.....	550
Great Falls, Mont	84×180	....	22 3½	....	.....	....
Copper Queen, Ariz.	42×216	....	....	....	.....	....
	42×240	....	....	....	.....	....
United Verde. Ariz	48×330	....	....	....	.....	....
Anyox, B. C.	50×360	....	....	12	.....	750
B. C. Copper Co., B. C.	51×360	72–3¼	....	12	.....	850
	51×240	72–3¼	....	12	.....	550
Tyee copper, B. C.	42×120	....	....	6	.....	200
	48×160	....	....	6	.....	300

[1] From Gowland's "Metallurgy of the Non-ferrous Metals," p. 83, and *Bull.* 209, Canad. Dept. of Mines.
[2] The Anaconda furnace is the largest yet constructed.

Blower Capacity

Iron Cupola Work.—500 cu. ft. of air per minute is required to melt 1 ton of pig iron per hour.[1]

Rotary blowers seem to require 5 hp. for every 1000 cu. ft. of air discharged at 1 lb. pressure.[2]

Copper Blast Furnaces.—At the Tennessee Copper Co. 1000 cu. ft. per minute per linear foot of furnace is the rule (56 × 270-in. furnace). At Mt. Lyell 20,000 cu. ft. at 64 oz. pressure is used per minute in a 54 × 210-in. furnace. At Great Falls, Mont., a furnace 84 × 180 in. at the tuyères receives 17,000 cu. ft. of air per minute. The Sasco, Ariz., smeltery used 13,000 cu. ft. per minute at 24 oz. pressure for a 43 × 192-in. furnace. Cananea used 12,000 cu. ft. per minute at 16 oz. pressure for a 48 × 210-in. furnace.

Converters.—The Copper Queen works figures that it requires 85,800 cu. ft. of blast to convert 1 ton of matte to blister copper.

Operations at the British Columbia Copper Co.'s Smeltery[3]

Blast furnaces.—The blast furnace building is 150 ft. long by 60 ft. wide and contains three water-jacketed blast furnaces placed end to end, with space between them for the minor axis of a 10 by 18-ft. oval settler. The two outside furnaces, Nos. 1 and 3, are each 51 by 360 in., while the middle one, or No. 2, is 51 by 240 in. in area at the tuyères. The vertical distance from the center of tuyères to the feed floor is 16 ft., and to the sole plate 37 in., the other furnace dimensions being as follows:

	30-ft. Furnace	20-ft. Furnace
Hearth area, sq. ft.	127.5	85
Center tuyères to tapping floor	5 ft. 3 in.	5 ft. 3 in.
Height of bottom jackets	9 ft. 0 in.	9 ft. 3 in.
Width of side jackets	3 ft. 4 in.	3 ft. 4 in.
Width of end jackets, bottom	3 ft. 8 in.	3 ft. 8 in.
Width of end jackets, bottom	6 ft. 2 in.	6 ft. 2 in.
Number of tuyères	72	48
Diameter of tuyères	4 in. bushed to 3¼ in.	
Area of tuyères	597.4 sq. in.	602.9 sq. in.
Tuyère area per square foot of hearth area	4.65 sq. in.	7.09 sq. in
Center line to center line tuyères	9.25 in.	9.25 in.

Water space in jacket, 4 in.; plate used on inside ⅝ in.; on outside, ⅜ in.

A Résumé of Furnace Operating Data, B. C. Copper Co.

Tons smelted per day, 2250.0; tons smelted per square foot of hearth area, average, 6.62; tons smelted per square foot of hearth area, maximum, 8.70; tons smelted per man per day,

[1] Hofman, "General Metallurgy," p. 777.
[2] *Ibid.*, p. 771.
[3] From a paper by F. K. Brunton, *Trans. A. I. M. E.*, 1915.

35.70; Cu, on charge, per cent., 0.8 to 1.2; Cu. in matte, per cent., 30.0 to 45.0; Cu in slag, per cent., 0.22 to 0.27; S on charge, per cent., 2.00; S burnt off, per cent., 85.00 to 90.00; coke used on charge, per cent., 12.00 to 14.00; coke ash, per cent., 20.00 to 28.00; blast, cubic feet per minute, 25,000; blast, temperature, atmospheric; cooling water for jackets, gallons per minute, 2500; men per 8-hour shift, 21.0; matte, per cent. of total charge, 1.65; matte, specific gravity, 5 to 0; slag, per cent., SiO_2, 38 to 45; Fe, 13 to 20; CaO, 20 to 26; Al_2O_3, 6 to 9; specific gravity, 3 to 3.2.

Kind of labor	Number of men	Wages per shift	Total wages per shift
Shift bosses	1	$5.25	$5.25
Furnace men	3	4.00	12.00
Furnace helpers	3	3.00	9.00
Slag motorman	1	3.40	3.40
Slag switchman	1	3.00	3.00
Charge motormen	3	3.15	9.45
Head loaders	3	3.15	9.45
Second loaders	3	3.00	9.00
Feeders	1	4.00	4.00
Binman	1	2.75	2.75
Power house	1	3.40	3.40
Total	21	....	$70.70

Costs of Copper Smelting—British Columbia Copper Co.

The following costs do not include overhead expenses, depreciation or insurance:

Cost per ton of smelting ore to matte[1]	$1.18
Cost per pound of copper of converting matte to blister	0.0048
Cost per ton of copper of converting matte to blister	9.60
Cost per ton of smelting ore to blister copper	1.23
Cost per ton of copper to produce blister copper	0.105
Cost of coke per ton of ore smelted to matte	0.851
Cost of flux per ton of ore smelted to matte	0.114
Cost of labor per ton of ore smelted to matte	0.15
Cost of power per ton of ore smelted to matte	0.033
Cost of supplies per ton of ore smelted to matte	0.03
	$1.178
Cost of coke per ton f.o.b. smelter bins	$6.00
Cost of flux per ton f.o.b. smelter bins	2.75
Cost of power per kilowatt-hour	0.0065

[1] NOTE.—The furnaces were slowed up with an excess of silica on the charge because of shortage of ore, hence the higher cost per ton of ore smelted to matte. They smelted only 6.55 tons per square foot of hearth area against 6.66 tons per square foot when the cost smelting was $1.084.

Briquette mill handled 1057 cars of blast-furnace flue dust and made 398 tons of briquettes.

Briquette cost $0.945 per ton for labor.

Distribution of smeltery payroll for same month and cost of labor per ton of ore smelted:

	Payroll distribution	Cost of labor per ton of ore smelted
Sample mill	$318.05	$0.00462
Bins	729.35	0.01060
Briquette	376.65	0.00546
Furnaces	6,508.35	0.0958
Slag disposal	1,413.65	0.0206
Linings	615.60	0.0078
Converters	1,016.85	0.0147
Crane	277.25	0.00403
Water system	224.65	0.00326
General surface	430.15	0.00624
Power house	585.60	0.00850
Total	$12,496.15	$0.18161

Jacket Water Required[1]

Hearth area, square feet	Water per hour, blowing in or out, gallons	Water per hour, normal running, gallons
3	900	460
5	1200	600
7	1450	950
9.5	2200	1100
12.5	3000	1300
18	4000	1500
24	5000	1800
30	6000	2000
36	7000	2200

Analyses of Copper Blast Furnace Gases

	O	CO	CO_2	SO_2	SO_3	N
Morenci, Ariz.	8.0	2.15	10.9	2.5	......	......
Globe, Ariz.	17.2	3.2	....	3.5	......	......
Copper Queen	10.0	(H_2O 3.5)	6.49	1.27	0.086	78.1
Tennessee[2]	.....	....	3.5	3.50	Tr.	.....

[1] Peters's "Modern Copper Smelting."

[2] As delivered to sulphuric acid chambers. According to Robert Sticht's data, all of the above results showing free oxygen are open to doubt, as he believes that oxygen can only be present in the free state in copper furnace gases when extraneous air is drawn into the testing apparatus via the charge doors.

FETTLING PRACTICE AT IMPORTANT NORTH AMERICAN SMELTING WORKS

Works at	Copper Cliff, Ont.	Great Falls, Mont.	Anaconda, Mont.	Tooele, Utah	Garfield, Utah	McGill, Nev.	Humboldt, Ariz.
Size of reverberatory furnace	19×112 ft.	15 ft. 9 in. ×42 ft.	19×110 ft.	19×102 ft.	20 ft. 4 in. × 123 ft. 5 in.	18 ft. 9 in. × 131 ft. 9 in.	19×60 ft.
Kind of material smelted	Calcines, 80% green ore and flue dust, 20%.	Roasted conc. and flue dust.	Roasted conc. and flue dust.	Low-grade calcines.	Roasted conc. flue dust and lime sand.	Roasted conc. flue dust, converter secondaries and lime rock.	Roasted conc. fine mine ore, raw conc., limerock and "cleanup."*g*
Present fettling materials	Green ore and calcines.	Crushed sandstone.	Crushed sandstone.*e*	Siliceous ores and crushed silica.*f*	Crushed quartz, siliceous tailings and siliceous ores.	Siliceous sulphide conc. or mill slimes.	Siliceous, 60%, ores and mill slimes.
How fettled	Dropped through roof.	Thrown in.	Thrown in.*e*	Dropped through roof.	Dropped through roof.	Thrown in.	Thrown in.*i*
Frequency of fettling	Continually.	About every 10 days.	Monthly.	Every 2 to 4 hours.	About every 5 days.	Daily.	Twice daily.
Tons of fettling used per furnace day	300*a*	2.8	1	8-10	5	27	About 5% of total charge.
Tons smelted exclusive of fettling	100–150*a*	200*b*	275	300	401	612	....
Total tons smelted	400–450	203	276	310	406	639	125
Fuel	Pulverized coal.	Gas.*c*	Coal.*e*	Coal.	Oil.*r*	Oil.	Oil.
Fuel ratio[1]	1:6	1:2*d*	1:4.25	1:5	0.70 bbl.	0.58 bbl.	1.1 bbl.
SiO_2 in slag	33–35%	37.9%	39.68%	39.0%	43.5%	42.6%	42%
Any trouble with siliceous floaters	No.	Occasionally.	No.	No.	Some floaters but not enough to make trouble.	No.	No.
How often are side walls repaired	Not since starting 8 mo. ago.		Once in 8 years.	Eight or nine months.	Eight months.	Semiannually	Not yet rebuilt.
Where is greatest wear in furnace	Roof.	At bridge.	Matte line near firebox.	Arch and sides 20 to 30 ft. from bridge.	In the 40 ft. nearest the firing end.	In the 50 ft. nearest the firing end.	Bridge and side walls, from 6 to 25 ft. from bridge.

FETTLING PRACTICE AT IMPORTANT NORTH AMERICAN SMELTING WORKS. *Continued*

Works at	Clifton, Ariz.	Douglas, Ariz., C. & A. Wks.	Douglas, Ariz., C. Q. Wks.	Hayden, Ariz.	El Paso, Texas	Cananea, Mex.
Size of reverberatory furnace	22×100 ft.	19×100 ft.	19×91½ ft.	19×112 ft.	19×100 ft.	19½×100 ft.
Kind of material smelted	Roasted conc., siliceous ores and fluxes.	Calcines and flue dust.	Calcines, flue dust and raw ore.	Roasted conc. and limerock.	Roasted conc. and flue dust.	Roasted conc. and flue dust.
Present fettling materials	Siliceous copper ores, and slag and matte.*h*	Copper ores, carrying S, 1.7 to 23.8%; SiO_2, 29.2 to 70.9%.	Copper Queen sulphur-bearing ores.*m*	Conc. and converter slag.	Siliceous ore.	High-grade conc. and siliceous ore.
How fettled	Dropped through roof.	Dropped through roof.	Dropped through roof.	Fed through special side openings.	Thrown in, except at bridge above which are fettling holes.	Dropped through roof.
Frequency of fettling	Each shift as required.	Practically continuously	Practically continuously	Practically continuously	Three times daily.	Practically continuously.
Tons of fettling used per furnace day	66	55	75	About 20% of total charge.	About 6% of total charge.	67*n*
Tons smelted exclusive of fettling	260	290	225	....	....	159
Total tons smelted	326*j*	345*l*	300	....	....	226
Fuel	Oil.	Oil.	Oil.	Oil.	Oil.	Oil.
Fuel ratio[1]	0.837 bbl.*k*	0.8 bbl.*k*	0.9 bbl.	....	....	0.995 bbl.
SiO_2 in slag	38.5%	....	34.8%	....	....	39.8%
Any trouble with siliceous floaters	Yes.	No.	No.	Occasionally.	Occasionally.	....
How often are side walls repaired	When making general repairs.	One repair in 8½ months.	Eight to nine months.	Six to nine months.	About once a year; except door jambs which are repaired about every 6 weeks.	Large repair about every six months; usually, one small repair during interim.
Where is greatest wear in furnace	Under second charge hole, 20 ft. from burners.	In first 30 ft. from the bridge wall.	At firing end.	In first 30 ft. from bridge.	In first 30 ft. from bridge.	First 40 ft. of arch and 20 ft. of side walls.

NOTES:

[1] Coal consumption expressed in ratio of tons of coal to tons of charge smelted; oil consumption expressed as barrels of oil per ton of charge smelted. *a* About. Most of the tonnage smelted is charged through fettling hoppers; when over 25 per cent. is dropped from regular charge hoppers a good fuel ratio is not maintained. *b* Exclusive of fettling and converter slag. *c* Gas-fired furnaces now being replaced by direct fired furnaces. *d* The coal used is a high-ash, high-sulphur bituminous coal of the following composition: H_2O, 7.9 per cent; volatile matter 23.8; fixed carbon 44.2; ash 24.1; sulphur, 4.5; B.t.u., 9310 per lb. *e* Now changing to coal-dust firing, and fettling through roof with calcined concentrates and flue dust. *f* Siliceous ores used for daily fettling; furnaces tapped down at intervals of 1 to 2 months and fettled with crushed silica. *g* From 20 to 22 tons of cold charge fed daily. *h* Average per furnace-day: ores, 18 tons; slag and matte, 48 tons. *i* Furnace equipped for fettling through roof, which will be practised when certain conveying devices are ready. *i* Solid charge. *k* Per ton of solid charge, and includes starting and stopping furnaces. *l* Solid charge; in addition about 100 tons of liquid converter slag are poured into the furnace. *m* Tonnage smelted increased from 230 to 300 tons when Bisbee sulphide ores (15.5 per cent. S) was substituted for 80 per cent. SiO_2 fettling. *n* Average per furnace-day in 1913; conc., 64 tons; siliceous ore, 3 tons. *r* Coal-dust firing being tried in one furnace.

Situation of works	Composition of reverberatory slags							Composition of fettling materials							S, %	Zn, %	Pb, %
	Au, oz.	Ag, Oz.	Cu, %	SiO_2, %	FeO, %	CaO, %	Al_2O_3	Au, oz.	Ag, oz.	Cu, %	SiO_2, %	Al_2O_3, %	Fe, %	CaO, %			
Copper Cliff, Ont.	*nil*	*nil*	0.50*o*	33–35	51.4*p*	......	......	*nil*	*nil*	5.50*o*	25.0	....	41.5	....	7.0	......	......
Great Falls, Mont.	0.001	0.1	0.45	37.9	43.0	4.0	9.0	.....	.....	.....	95.0	1.8	0.7	1.1	....	......	......
Anaconda, Mont.	0.0006	0.19	0.39	39.7	42.3	4.6	7.0	.....	.....	.....	97.5	1.7	0.1	0.2	....	......	......
Tooele, Utah	0.005	0.40	0.35	39.0	46.9*b*	4.5	......	0.40	20.00	0.40	75.0	....	6.5	3.0	0.5	......	1.5
Garfield, Utah	0.001	0.035	0.35	43.5	27.0	18.0	7.5	0.10	7.0	0.20	85.6	1.2	2.9	0.8	....	......	0.4
McGill, Nev.	0.003	0.008	0.345	42.6	36.3	10.3	6.5	0.02	0.07	3.26	66.1	8.8	7.0	0.9	6.7	......	......
Humboldt, Ariz.	......	......	0.33	42.0	29.6*b*	15.0	......	.....	.....	.....	60.0	....	....	....	....	......	......
Clifton, Ariz.	......	......	......	38.5	42.4	5.1*c*	9.7	.....	.....	7.30	60.0	10.1	6.5	0.8*q*	2.1	Siliceous ores.	
								.....	.....	9.50	29.1	6.3	26.6	7.6*q*	4.5	Slag and matte.	
Douglas, Ariz., C. & A.	......	......	0.5	34.0	46.0	7.0	6.0	0.033	0.45	4.2	29.2	7.1	24.7	0.7	23.8	Sulphide ore.	
								0.004	0.36	5.4	29.5	12.4	22.7	3.2	1.7	Oxide ore.	
								0.107	5.00	3.0	70.9	6.6	6.3	1.5	3.6	Siliceous ore.	
Douglas, Ariz., C.Q	......	0.10	0.487	34.8	43.1	1.9	8.6	0.02	1.06	6.45	23.2	7.5	25.4	1.9	15.5	......	......
Hayden, Ariz.	......	......	......	......	......	......	......	.....	.....	18.0	26.0	5.0	22.0	....	24.0	Concentrates.	
								.....	.....	1.5	23.0	4.0	51.0	1.0	1.5	Converter slag.	
El Paso, Tex.	......	......	......	......	......	......	......	.....	.....	.....	60.0	16.0	1.5	....	3.0	......	......
Cananea, Mex.	*nil*	0.12	0.48	39.8	37.5	4.5	10.4	0.013	2.1	37.81	16.0	4.7	14.0	0.5	22.4	Concentrates.	
								0.001	0.35	3.54	50.9	10.2	12.6	2.8	6.5	Ore.	

o Cu-Ni. *p* Reported as Fe: converted to FeO for comparison. *q* CaO-MgO.

Fettling Practice at North American Smelting Works[1]

The fettling of reverberatory furnaces has undergone marked change in the last 8 or 10 years. This is well illustrated in the table on the preceding pages, which has been compiled from replies received from officials of the leading smelting works in North America that use reverberatory furnaces. The table presents in concise form much interesting data regarding the reverberatory furnaces of the country, but the most striking feature is the diversity in fettling practice between the older and newer plants. Most of the newer works fettle the furnaces through the roof, while the older plants throw the fettling in through the side doors. The older works still use for the most part quartz or other high-silica material, and naturally use this fettling as sparingly as possible. The newer plants, on the other hand, drop almost any material on the sidewalls and in large quantities, the idea being that the sidewalls will be protected if a sufficient amount of cold materials be dropped thereon. It should be remarked, however, that most of the plants that fettle through the roof use ores or products containing sulphur, some carrying the revolution so far as to use raw concentrates, or converter slag or matte cleanings—materials that a few years ago would have seemed absolutely heretical.

When the fettling was dropped through the roof on the side walls in great quantities, some of it naturally floated out into the furnace, and after some experimentation it was found that raw ore, floating off with the slag, during skimming, was increasing the metal loss; this led to the use of siliceous ores containing copper as sulphide, in which form it would be readily removed by the heat of the furnace. This practice has been carried still farther by the use of ores carrying as much as 15 per cent. sulphur as at Douglas, and also by the use of raw concentrates, as at Cananea and elsewhere, confirming the hypothesis that a large quantity of cold materials was what was needed to protect the side walls.

It should be borne in mind in consulting the table that much of the data is approximate and subject to the personal equation of the official answering the series of questions submitted. For example, in the matter of tonnage figures, it may readily be that one official is reporting the tonnage of his furnace under the best normal operating conditions, whereas another may have given the average tonnage actually smelted in a given month, thus including interruptions or accidents that invariably reduce the actual tonnage smelted below the average of the furnace under the best conditions. Hence the tonnages given should be merely regarded as approximate. In several instances officials went to the trouble to point out that molten converter slag was not included in tonnage reported. This is what would normally be expected, but it is not clear whether this is the case in every instance. The answers to the various questions have been inserted in the table in the original phraseology of the reporting

[1] *Eng. and Min. Journ.*, Oct. 17, 1914.

official wherever that was consistent with a proper interpretation by comparison with other data submitted. The subsidiary table showing the analyses of the slags and of the fettling materials will be of interest, and some of the other incidental information will attract attention, particularly that touching on the practice in Montana, where some important changes are taking place.

Coal-dust Firing of Reverberatories[1]

It was finally adopted at Copper Cliff, however, designing furnaces especially to meet the requirements by eliminating right-angled bends in the flues and placing the skimming door at the side instead of the end. The waste-heat boiler was made a secondary consideration. The first smelting showed no difficulty with the fuel, and as improvements were gradually made the smelting became more efficient. In the first 3 months of 1914 the fuel ratio was 5, 5.65 and 6.77, respectively. The method of feeding has been changed. At first it was done through hoppers near the fire end, but is now done almost entirely through pipes in the side walls. Coal dust is introduced through five pipes 5 in. in diameter. It is first dried and then ground so that about 95 per cent. passes a 100-mesh and 80 per cent. passes a 200-mesh screen. The great advantage found in this method of firing is the absence of breaks in the temperature curve due to grating or cleaning the hearth, and as a consequence a greatly increased tonnage and fuel ratio.

At Anaconda coal-dust firing was tried in June, 1914, in a furnace 124 ft. by 21 ft. The method of charging was similar to that used at Copper Cliff. From the experience gained in this work, MR. BENDER lays down the following requisites for successful use of coal dust: (1) The coal should be dried before pulverizing, containing not more than 1 per cent. moisture; (2) fine pulverization affords increased area and higher thermal efficiency, 95 per cent. should pass a 100-mesh screen and 85 per cent. a 200-mesh; (3) the quantities of coal and air delivered to the furnace should be carefully controlled in order to secure complete combustion; (4) the coal should contain enough volatile combustible matter to give the required combustion; a standard for cement work is 30 per cent.; (5) the furnace should be properly designed and equipped, and (6) provision must be made for taking care of the ash. Based on past experience, some changes will be made in the new equipment for coal-dust reverberatory firing at Anaconda. The furnaces will be 144 ft. by 25 ft., with a flue area of 48 sq. ft. Matte will be tapped at the front. The skimming plate will be 12 in. higher than in other furnaces, the top of the plate being 24 in. above the tap hole. Recent records for a week at Anaconda indicate the efficiency of coal-dust firing; the average tonnage per day was 542.7, with a fuel ratio of 7.5.

[1] "*Bull.*" *A. I. M. E.*, January, 1915.

Reverberatory Practice

Some of the essentials of good ore-smelting reverberatory practice are thus summed up by R. E. H. Pomeroy.[1]

1. Careful preparation of the charge by adequate mixing of all ingredients before charging.
2. Addition of enough lime rock, preferably coarse, to produce an active boiling in the furnace.
3. Maintaining a deep bath of molten matte to equalize and distribute the heat over the whole of the hearth.
4. Frequent skimming so as to carry only a thin layer of slag over the matte bath.
5. Operating the furnace for the best smelting conditions, ignoring the waste-heat boilers as factors in the power supply.

Factors affecting the life of the furnace:

1. The furnace roof set high over the hottest portion of the hearth.
2. Frequent fettling to protect the side walls.
3. Frequent charging and active charge mixtures to avoid floater and blanket formation requiring excessive firing.

The largest copper-ore-smelting reverberatory, so far as known, is the new one at Anaconda, with a 25 × 144-ft. hearth. A furnace 178 ft. long has been built for settling reverberatory slags. The largest copper-refining reverberatory is, so far as I know, 17 ft. × 33 ft. 8 in., and has cast a charge of 550,000 lb. These figures are due to the courtesy of A. Clayton Clark.

Electric Smelting of Copper Ores

Claude Vattier's Livet Experiments, 1903[2]

	Analyses		
	Ore	Matte	Slag
Cu	5.10	47.90	0.10
S	4.13	22.96	0.57
Fe	28.50	24.30	32.50
Mn	7.64	1.40	8.23
SiO_2	23.70	0.80	27.20
Al_2O_3	4.00	0.50	5.20
CO_2	4.31	....	....
CaO	7.30	....	9.90
MgO	0.33	....	0.39
P	0.05	....	0.06
	85.06	97.86	94.15

Current, 4750 amp. at 119 volts.
One metric ton of ore smelted per hour.
Electrode consumption, 6.25 kg. per hour.

[1] *Bull. A. I. M. E.*, February, 1915.
[2] J. W. Richard's "Metallurgical Calculations," Vol. III.

According to D. A. LYON and ROBERT M. KEENEY, no copper ores are treated in the electric furnace in this country at the present time. It is reported, however, that in Norway trial smeltings of copper ores with an electric furnace of 1000 hp. and an estimated producing capacity of 2000 tons of copper per annum have been conducted at the Ilen Smelting Works, Trondhjem, and we understand that it is the intention to smelt copper ores regularly at this plant in the electric furnace.

Converter Output at Great Falls

In the article on the Old Dominion smelting works, at Globe, Ariz., in the *Journal* of June 6, 1914, attention is directed to the large daily output obtained in the Great Falls type converter used at this plant. The statement is made that this daily copper output, *i.e.*, 60 tons is about double that reported last year by MESSRS. WHEELER and KREJCI for shells of the same size at Great Falls, Montana.

COPPER OUTPUT OF CONVERTERS AT GREAT FALLS

Period	Tons copper produced per converter day	Per cent. cu. in. matte	Min. per ton of copper	Tons of iron and sulphur oxidized per converter day	Tons of ore used per converter day
Feb., 1914.	95.20	36.4	15.13	176	65.3
Mar., 1914.	89.27	33.8	16.13	186	71.4

While this is probably a record figure for upright shells, 12 ft. in diameter, it does not approximate the output obtained from the Class V or 20-ft. converters now in use at Great Falls. In the 20-ft. converters the average output of copper was over 95 tons per day in February, and nearly 90 tons in March when converting a 34 per cent. matte. In addition, from 25 to 30 tons of cold matte and cleanings are treated per converter day, and operations during the months cited were handicapped on account of reconstruction work; it is expected that the output will be increased when normal running conditions are restored. In the article "Great Falls Converter Practice,"[1] MESSRS. WHEELER and KREJCI reported that the 20-ft. converter produced at the rate of 4.31 and 4.77 tons of copper per converter hour when in operation, or at the rate of 103.4 and 114.5 tons of copper per day, respectively; this was when converting a 38 to 39 per cent. matte.

[1] *Bull. A. I. M. E.*, Feb., 1914.

American Converters—Old Style Acid Lined[1]

Company, type	Outside height, ft.	Outside diameter, ft.	Blast pressure, lb. per sq. in.	Initial charge, lb.	Maximum charge, lb.	Blows per 24 hours	Wt. of shell and lining	Number of tuyères
Parrot and M.O.P.Co.'s..	8.5	5	11	2,500	9,000	16	16,000	16
Anaconda.....	10	6	13	7,000	17,000	12	22,000	16
Great Falls....	13	7	16	10,000	22,000	10	26,000	18
Stalmann.....	8	5	10	3,000	9,000	14	17,000	10
Copper Queen.	7.25	5.67×8	5.5	4,000	10,000	12	......	......

Canadian Converter Practice[2]

Company	Type	Stands	Shells	Dimensions
Canadian Copper Co.	Basic. Peirce-Smith special............	5	5	10′ 0″×37′ 2″
Mond Nickel Co....	Basic. Peirce-Smith standard..........	2	2	10′ 0″×25′ 10′
Granby Cons. M. & S. Co.: Grand Forks.....	Basic. Power & Mining Mchy Co. acid shells.............	3	10	84″×126″
Anyox...........	Basic. Great Falls type..............	3	3	12′ 0″×5′ 9″
B. C. Copper Co....	Acid. Allis-Chalmers	2	5	84″×126″

Converting at the British Columbia Copper Co.'s Smeltery[3]

There are two hydraulic converter stands; seven 84 × 126-in. converter shells; a 40-ton NILES electric traveling crane; a 6-ft. CARLIN silica mill, motor driven; a pneumatic tamping device; copper casting trucks, etc. A converter lining lasts two to three charges. The matte runs from 30 to 45 per cent.

The converter department produced per day about 30,000 lb. of blister copper, carrying about 7 oz. of gold and 30 of silver per ton. It required a crew of 21 men which, divided as follows into two 8-hour shifts, was able to handle all the matte produced:

Kind of labor	Day shift, 7 A.M. to 3 P.M.	Afternoon shift, 3 P.M. to 11 P.M.
Foremen.........	1	0
Converters.......	2	2
Crane...........	2	2
Laborers.........	3	1
Lining...........	5	3
Total.......	13	8

[1] From PETER'S, "Modern Copper Smelting."
[2] *Bull.* 209, *Canadian Dept. of Mines.*
[3] From a paper by F. K. BRUNTON, *Trans. A. I. M. E.*, 1915.

Converter Blast.—According to Sticht, about 100,000 cu. ft. of air is required per long ton of copper produced from 50 per cent. matte and 165,000 cu. ft. of air for a long ton of copper from 40 per cent. matte. At one American works 183,000 cu. ft. of air is required per 2000 lb. of Cu produced.

Converter Costs.—As a rough basis for estimates on new work, $4.50 per ton of matte could be taken as a minimum, and $9.50 should be an outside figure for acid converting. Basic should be a little cheaper.

Lining.—About 2 tons of copper will be produced per ton of lining in the acid converter.

Gases.—The following analysis of gas passing through a converter flue is given by Dunn (*Trans. A. I. M. E.*, 1913): SO_2, 2.845 per cent.; SO_3, 0.0515; CO_2, 0.2084; H_2O, 1.061; As_2O_3, 0.00073; O, 12.04; N, 83.64 per cent.

Sulphuric-Acid Manufacture

As the regions surrounding smelteries grow more densely populated, the difficulties caused by the discharge of sulphuric acid and sulphur dioxide into the atmosphere and the probability of being forced into sulphuric-acid manufacture increase. The contact-acid process does not seem successful for smelting plants, probably because of the arsenic in the fumes poisoning the catalyst. In the chamber process one has the ordinary chambers, the Meyer tangential system, the Falding high-chamber, and the still experimental lead spirals to choose from. The Falding system as adopted at the Tennessee Copper Co. was described by its inventor in the Eng. and Min. Journ. of Sept. 4, 1909, p. 443. In that article he makes the following comparison between the systems:

	Chamber space, cu. ft.	Ground area, sq. ft.	Weight of lining, tons
Old System	174,960	12,936	112
Meyer tangential	174,480	11,938	110
Falding	175,000	4,096	66.5

Acid manufacture at the Ducktown Sulphur, Copper & Iron Co.'s plant was described in the Journal of May 28, 1910, by W. H. Freeland and C. W. Renwick. That plant was designed for a capacity of 160 tons of 60° B. acid per day. Under normal conditions the gases delivered to the chambers analyze: SO_2, 3½ per cent.; CO_2, 3½ per cent.; and SO_3 trace. Temperature control of the gases is attained by small kite-shaped flues through varying lengths of which the gases can be run, until they are sufficiently cool. There are two Glover's towers, each 12 ft. square and 45 ft. high. Following these are four hard-lead fans (10 per cent. antimony) then two sets of eight chambers each. Each chamber is 96 ft. long, 22 ft. 8 in. wide and 30 ft. high. Special arrangements are said to be in-

troduced here to take care of the carbon dioxide in the gases.[1] Six Gay-Lussac towers are used for recovery of the nitrous acid.

In a discussion of pyritic smelting and acid manufacture by Falding and Channing (Eng. and Min. Journ., Sept. 17, 1910) the necessity of a uniform composition of gas is insisted upon by these authors, and the general point made that an acid plant drawing its gases from several furnaces will more probably be successful than if it draws its gas from one.[2]

The Anaconda Copper Co. in 1915 constructed a 100-ton acid plant, but this was as an adjunct to a leaching plant, and not to use blast-furnace gases. It was described by E. P. Mathewson in the Eng. and Min. Journ. of April 24, 1915.

Two 7-hearth Wedge roasters 22 ft. 6 in. inside shell diameter are used and the gases are led into a dust absorber 32 ft. in diameter by 44 ft. high over all. There are six niter pans. Gases from these mix with the sulphur gases in an octagonal Glover's tower 16 ft. across × 51 ft. high. There are 23 cooling chambers, 11 ft. diameter × 36 ft. high and six 40 × 96 × 36 ft. high. These are arranged five round, rectangular, three round, rectangular, three round, two rectangular, three round, rectangular, three round, rectangular, six rectangular. A hard-lead fan, 8 ft. in diameter and 4-ft. face follows the first five round chambers.

There are 21 Gay-Lussac towers, circular in section, 7 ft. in diameter by 38 ft. high. They are constructed, except for the lead pans, of Duro-tile blocks laid in acid-proof cement with a packing of 72-hr. coke. The chamber space is 18 cu. ft. per pound of sulphur per day.

Miscellaneous Data for Lead Metallurgy[3]

Zinc Required for Desilverizing Lead

Silver in lead, per cent.	Zinc required, per cent.	Silver in lead, per cent.	Zinc required, per cent.
0.025	1.25 (*a*)	0.3	2.00 (*a*)
0.05	1.33 (*a*)	0.38	1.84 (*b*)
0.1	1.5 (*a*)	0.51	1.96 (*b*)
0.15	1.66 (*a*)	0.84	2.45 (*b*)

[1] The matter of the ill effect of carbon dioxide in chamber work is by no means settled. Lunge says one Bohemian works with which he was acquainted made acid without trouble or special precautions from material carrying 10 per cent. of bituminous matter.

[2] In plants making sulphuric acid from pyrites, the inlet gases are considered to be best at 8.8 per cent. SO_2, 9.6 per cent. O_2; when burning brimstone, the gases should contain 10.65 per cent. SO_2, 10.35 per cent. O_2.

[3] Schnabel's "Handbook of Metallurgy." The Macmillan Co.

(*a*) According to Illing. (*b*) According to June.

Note.—At 350°C. lead dissolves 0.6 per cent. of Zn; at 650° it will dissolve 3.0 per cent. of Zn.

TYPICAL PRODUCTS OF LEAD SMELTING

	Speiss, Leadville	Speiss, St. Andreasberg	Matte, Pueblo	Matte, Pueblo	Raw matte, Clausthal	Roasted matte, Clausthal
Ag....	0.0085	....	....	....	0.0299	0.0327
Au....	tr.	....	....	....	....	....
Cu....	0.3628	18.37	20.40	10.35	4.620	4.123
Pb....	1.4935	66.84	8.50	12.45	10.665	10.492
Mo...	0.2110	....	....	....	....	....
Fe....	60.578	0.22	41.20	42.50	53.112	52.411
Zn....	tr.	0.04	1.50	3.10	2.110	2.459
Ni....	0.0876	} 0.13	....	....	0.312	0.350
Co ...	....					
S.....	5.1891	....	26.30	26.40	....	....
As....	31.4725	tr.	tr.	0.12	26.877	0.613
Sb ...	tr.	3.60	tr.	0.05	0.267	0.128
SiO_2..	....	....	0.20	0.30	0.510	1.486
CaO..	....	....	....	0.15	0.383	0.336
Sn....	....	10.60	0.16	0.21	....	....
Bi....	....	tr.	....	....	....	....
Mn...	....	....	1.40	3.30	0.385	0.317
O.....	....	....	....	....	....	22.966
SO_3...	....	....	....	....	....	4.225

Effect of Steam on Molten Lead[1]

If the temperature of the lead be below the melting point of zinc, steam will bring to the surface a zinc crust with some of the silver.

If the temperature of the lead be slightly above the melting point of zinc, the steam will cause a thorough mixing of the zinc and lead.

If the temperature be between a dark red and an incipient cherry red, the steam will cause a scum to rise, containing about 3 per cent. of zinc, which does not, however, take any silver away from the zinc.

If it be a clear cherry red, the zinc will decompose the steam; the zinc oxide, mixed with lead oxide, collects as a powder on the surface of the lead.

[1] HOFMAN'S "Metallurgy of Lead."

Softening Lead[1]

	Clausthal		Lautenthal		Freiberg		Denver	
	Before drossing	After drossing	Before drossing	After drossing	Before drossing	Liquated dross (5%)	Dross before liquating	Dross after liquating
Pb	98.92944	99.0239	98.96475	99.1883	96.667	62.40	53.0	50.0
Cu	0.1862	0.1096	0.2838	0.0907	0.940	17.97	18.2	26.8
Cd	Tr.	None	Tr.	None	......	......	......	....
Bi	0.0048	0.0050	0.0082	0.0083	0.066	None	......	Au = 0.30 oz.
Ag	0.1412	0.1420	0.1430	0.1440	0.544	0.17		75.0oz.
As	0.0064	0.0053	0.0074	0.0032	0.449	2.32	......	7.31
Sb	0.7203	0.7066	0.5743	0.5554	0.820	0.98	......	0.18
Sn	None	None	None	None	0.210	0.04	......	....
Fe	0.0064	0.0042	0.0089	0.0048	0.027	0.43	......	....
Zn	0.0028	0.0017	0.0024	0.0015	0.022	0.07	......	....
Ni	0.0023	0.0017	0.0068	0.0038 }	0.0055	1.09	......	....
Co	0.00016	Tr.	0.00035	Tr. }				
S	....	....	....	....	0.200	4.00	2.0	3.6
O	....	....	....	....	......	1.87	......	....
Slag,	ash, hear	th mate	rial......	....	......	8.66	1.8	4.8

Pattinson's Process—Crystallization

(Ounces of Silver per Ton)

In the molten lead before crystallization	In the crystals	In the liquid lead
205.33	113.74 – 135.91	298.95
213.49	92.75 – 109.8	313.83
281.34	119.58 – 198.33	422.91
288.16	113.74 – 181.99	446.24
420.57	198.91 –	560.57
609.57	586.53 –	659.15
615.15	503.99 – 646.31	655.65

Results from experiment—not particularly concordant. "Berg- und Hutten-männische Zeitung," 1862, p. 251.

Zinc Table for a 30-ton Kettle[2]

First Addition of Zinc (to Remove Gold)

Up to 0.10 oz. gold per ton, 250 lb. zinc.
From 0.10 to 0.30 oz. per ton, 300 lb. zinc.
From 0.30 to 0.50 oz. per ton, 350 lb. zinc.
From 0.50 to 0.70 oz. Au, 400 lb. zinc.
From 0.70 to 0.90 Au, 450 lb. zinc, etc., etc.

[1] Hofman, "Metallurgy of Lead."
[2] By Eurich, taken from Hofman's "Metallurgy of Lead."

Second addition to bring silver contents to 40 oz.		Third addition to bring silver contents to 1 oz.		Fourth addition to bring silver contents to 0.1 oz.	
Oz. Ag per ton	Lb. zinc	Oz. Ag per ton	Lb. zinc	Oz. Ag per ton	Lb. zinc
40	15	5	225	0.2	60
50	50	7	265	0.3	75
60	100	10	320	0.4	90
70	160	15	400	0.5	105
80	200	20	450	0.6	120
90	245	22	470	0.7	135
100	285	24	485	0.8	150
110	315	26	500	0.9	165
120	345	28	512	1.0	180
130	365	30	530	1.5	225
140	390	32	540	2.0	330
150	415	34	555	2.5	390
160	440	36	570	3.0	450
170	460	38	585	3.5	510
180	475	40	600	4.0	562
190	495	42	615		
200	515	46	630		
....	....	48	640		
....	....	50	655		
....	....	52	670		
....	....	54	680		
....	....	56	695		
....	....	58	710		
....	....	60	734		
....	....	62	747		

Before desilverizing lead must be softened, for copper must be removed completely, arsenic to a trace, antimony to not over 0.75 per cent. Copper and tellurium combine with zinc even more readily than does silver.

NEWTON'S experiments at Maurer (*Bull. A. I. M. E.*, 1915, p. 174), conclusively showed that 535°C. is the best temperature at which to remove the zinc crusts. CARPENTER and WHITLEY have shown that there is but one chemical compound formed between zinc and silver; this is Zn_3Ag_2, freezing at 665°C. It is soluble in lead at high temperatures.

Effect of Impurities on Refined Lead[1]

Antimony and arsenic—render lead hard and less malleable. Said to render lead more easily attacked by hot sulphuric acid when antimony is over 0.2 per cent. This seems unreasonable. For corroding, lead may not have over 0.005 per cent. Sb. Tin, arsenic and antimony are oxidized in that order, and the products from softening lead may be separately worked up for these elements.

Bismuth—0.118 to 0.352 makes lead hard, somewhat crystalline and more fusible. Over 0.02 unfits lead for corroding.

Cadmium—tends to protect lead against sulphuric acid.

Iron.—Lead containing 0.07 per cent. Fe does not seem to lose in either softness or malleability. Corroding lead ought not to carry over 0.003 per cent. Fe.

Nickel and Cobalt.—These can readily be eliminated by slow fusion.

Tin—makes lead light gray, hard and increases fusibility. Is readily removed by heating in air.

Zinc.—Corroding lead ought not to carry over 0.003 per cent. Zn.

Typical Lead Smelting Furnaces

	Dimensions at tuyères, inches	Blast pressure	Smelting column, feet	Capacity per 24 hr.	Remarks
U. S. Smelting Co., Midvale[1]	45×160	.....	16–18	200	Mech. feed
Tintic Sm. Co., Tintic, Utah[1]	48×160	32–34	......	....	Coke, 12%
A. S. & R. Co., Pueblo, Colo.[1]	48×148	34	......	150	Mech. feed
A. S. & R. Co., Denver, Colo.[1]	42×144	32	18	120–150	....
A. S. & R. Co., Murray, Utah[1]	48×164	34	20	166	Coke, 12%
Port Pirie, Australia[1, 3]	62×212	30	21	150	....
A. S. & R. Co., Perth Amboy, N. J.[1]	44×128	35	16	140	Coke, 12%
Laurium, Greece[1]	48×160	35–40	20	250–275	Coke, 14%
Herculaneum, Mo.[2]	42×192	.....	......	....	....
Peñoles, Mapimi., Mex.[2]	46×162	42	22	150	Coke, 13.1%
A. S. & R. Co., Perth Amboy, N. J.[2]	42×220	.....	......	....	....
A. S.&R. Co., Monterey, Mex.[2]	44×236	.....	......	....	....
A S.&R. Co., Chihuahua, Mex.[2]	46×202	.....	......	....	....

[1] Hofman, "Metallurgy of Lead."
[1] From Gowland's "Metallurgy of the Non-ferrous Metals," p. 155.
[2] Private notes.
[3] It would appear that the Port Pirie furnace is the largest operating.

ZINC SMELTING[1]

Effect of Impurities in Smelting:

Alumina—may be objectionable, as zinc spinel may be formed.

Arsenic and Antimony.—These are partly reduced and volatilized, and appear in traces in the spelter.

Cadmium.—Cadmium is more easily reducible and more volatile than zinc, and collects in the first dust and metal, which can then be used as a source of this metal.

Calcium.—Lime alone is beneficial, as it tends to decompose zinc sulphide. See **Silica,** above.

Fluorspar.—This is an undesirable constituent because it forms fusible slags which attack the retorts.

Gold and Silver.—These remain chiefly with the retort residues and can be recovered from them by resmelting.

Iron and Manganese—should not be present as sulphide, as it corrodes the retort. Also forms fusible slags with silica, which corrode the retort. Ten per cent. Mn + Fe represents about the upper limit of safety.

Lead.—The chief objection to lead is that its compounds are reduced and some lead distils over with the zinc.

Magnesia—acts much like lime, but magnesian slags are less fusible than calcareous.

Silica—is inert alone, of no particular consequence when lime is present, but is harmful if both lime and iron are constituents of the charge since ferrous-lime silicates are extremely fusible.

Sulphur—decreases the yield of zinc, since the sulphide is not decomposed by carbon. Ferrous sulphide corrodes the retort.

In general, either highly acid or highly basic charges must be used, there must be a little space above the charge, and the charge should not be too finely pulverized.

The formation of zinc spinel occurs to a larger extent in handmade than in machine-made retorts; it is diminished greatly by addition of coke to the mass used for making the retorts. During smelting the slag takes up considerable quantities of silica and alumina from the retorts, and a viscous layer, intermediate in composition between the slag and the retort, is formed, which tends to prevent rapid destruction of the latter. It is only at the higher temperatures prevailing toward the end of the distillation that there is any pronounced destructive action of the slag on the retorts. The absorption of zinc oxide by the clay used for making the retorts, and its fixation as aluminate, increases with the pressure, temperature, and time.[2]

[1] W. R. Ingalls, "Metallurgy of Zinc and Cadmium."
[2] *Metall. und Erz.*, 1914, pp. 333, 337, 412, 553.

Miscellaneous Data for Zinc Smelting

Blue Powder Production (Zinc Smelting)

Blue powder	I	II	III	IV	V	VI
Zn	(a)90.11	(b)94.04	(a) 91.50	(c)95.50	(d) 88.80	(e)91.29
Pb	0.82	2.50	0.50	1.50	1.90	1.98
Fe	0.10	0.30	0.18	....	1.32	0.79
Cd	0.005	1.30	0.50	....	1.80	0.52
As, Sb	Nil	....	0.16	....	Tr.	Tr.
C	3.33	....	?	2.50	4.10	3.11
Insol		0.50	....	....	Tr.	Tr.
Zinc ore:						
Zn	47.00	46.60	43.00	50.00	48.50	44.50
Pb	3.80	6.60	1.80	5.50	6.50	9.30
Fe	10.34	5.50	8.40	8.50	8.30	12.50
Cd	0.005	0.06	0.10	?	0.18	0.25
S	1.08	1.80	1.50	?	2.50	3.40
As	Tr.	Tr.	0.05	?	0.02	0.02
Sb	Tr.	Nil	0.03	?	0.04	0.03
CaO	4.00	2.80	3.50	4.00	6.00	4.50
MgO	0.60	0.80	1.20			
SiO_2	10.00	13.80	22.00	6.00	13.80	13.90
	A	*B*	*C*	*H*	*I*	*I*

(a) A small portion in the form of ZnO. (b) Metallic zinc, 88.74 per cent.; ZnO, 6.60 per cent. (c) Metallic zinc, 85.34 per cent.; ZnO, 12.66 per cent. (d) Metallic zinc, 79.16 per cent.; ZnO, 11.26 per cent. (e) Metallic zinc, 85.24 per cent.; ZnO, 7.54 per cent.

W. R. Ingalls, "Metallurgy of Zinc and Cadmium."

Residues produced	I	II	III	IV	V	VI
Zn	4.00	2.50	3–7	4.00	3.40	4.20
Pb	5.00	8.50	1.26	10.00	8.10	9.50
Fe	16.55	14.50	?	?	?	?
Ag	0.016	?	?	0.01	0.05	0.085
Cu	0.05	?	?	....	?	?
Cd	Nil	?	?	....	?	?
As	Nil	?	?	....	?	?
Sb	Nil	?	?	....	?	?
S	?	4.00	?	?	2.10	3.50
CaO	2.50	2.50	?	8.00	?	?
MgO	0.45	1.50	?	?	?	?
SiO_2				17.50	?	?
C	50.00	60.00	?	?	?	?
Al_2O_3				?	?	?

On attempting a jigging of the above, these products were obtained:

Zn	3.87	5.00	6–7	3–15	8.0–12.0	2.50–7.0
Pb	24.25	13.16	40–50	4–30	30.0–35.0	10.0–48.0
Ag	0.032	0.016	....	....	0.04–0.05	0.049–0.16
Fe	42.75	20.68	15–20	....	....	11.77–24.0
SiO_2	18.66	44.67	15–20	....	....	12.75–60

Retort Duty.—According to INGALLS, a production of about 4¼ tons of spelter per retort per year is a safe estimate.

Glazing.—Sometimes the retorts are glazed when dry in order to make them impervious to the passage of gas. Lead glazes may not be used; more often porcelain and salt glazes are used. The porcelain glaze consists of 84 parts ground feldspar, 35 parts calcium carbonate, 26 to 91 parts china clay and 54 to 204 parts quartz sand. It is not necessary that the glaze be quite white. The glaze is made into a mixture with gum arabic, dextrine or some other paste and painted on the inside of the retort to a thickness of about ⅛ in.

CADMIUM-BEARING FLUE DUSTS[1]

	Silesia works		Total	Godulla works		Total
	Soluble	Insoluble		Soluble	Insoluble	
ZnO	17.144	7.192	24.336	10.991	9.532	20.523
PbO	......	6.285	6.285	......	8.980	8.980
CdO	0.874	1.147	2.021	1.120	1.518	2.638
TlO	0.006	....	0.006	0.006	....	0.006
FeO	1.896	....	1.896	1.676	....	1.676
MnO	1.332	0.042 (Mn_3O_4)	1.376	0.481	1.591 (Mn_3O_4)	2.072
Fe_2O_3 }	2.900	9.043	15.058	2.940	15.928	18.868
Al_2O_3 }		3.115		1.191	4.601	5.792
CaO	0.714	0.478	1.192	0.464	1.071	1.535
MgO	0.168	0.440	0.608	1.337	0.858	2.195
As_2O_3	......	0.401	0.401	......	1.280	1.280
P_2O_5	......	0.263	0.263	......	0.394	0.394
SO_3	20.430	6.612	27.042	13.320	9.061	22.381
H_2O	11.400	....	11.400	4.850	....	4.850
Residue	......	7.765	7.765	......	6.804	6.804

Smelting Zinc Ores by Electricity

The following estimate of electric zinc smelting is given by DORSEY A. LYON and ROBERT M. KEENEY, in a paper before the San Francisco meeting of the A. I. M. E., September, 1915:

Although more progress has been made hitherto in the electric smelting of zinc ores than in that of any of the non-ferrous metals except aluminum, and metals forming ferro-alloys, such as silicon, chromium and tungsten, the process is nevertheless still largely in the experimental stage. There is no plant operating on a commercial scale except the Trollhättan works, taking from 10,000 to 13,000 hp. There are about twenty-four furnaces installed at this plant, each requiring from 400 to 1200 hp. The same company, the Norse Power & Smelting Syndicate, also has a smaller plant near Trolhättan at Sarpsberg, where there are seven small furnaces. One other small commercial plant is in course of erection at Keokuk, Iowa, by the Johnson Electric Smelting Co. It appears that the experiments conducted at Hartford, Conn., for several years have

[1] SCHNABEL'S "Handbook of Metallurgy." The Macmillan Co.

Zinc Distillation Temperatures

According to Ingalls

In the retort: beginning, 781; end, 1188.
In the furnace: 1067; end, 1309.
Interior of furnace near middle wall where the gas is introduced, about 1315°C.

Capacity and Weight of Cylindrical Retorts[1]

Length outside, in.	7 in. diam. inside			8 in. diam. inside		
	Outside vol., cu. in.	Inside vol., cu. in.	Wt. lb. (a)	Outside vol., cu. in.	Inside vol., cu. in.	Wt. lb. (a)
46	2926	1693	86.3	3613	2212	98.1
47	2990	1732	88.0	3691	2262	100.0
48	3054	1770	89.9	3770	2312	102.1
49	3117	1809	91.6	3848	2362	104.0
50	3181	1847	93.4	3927	2413	106.0
51	3244	1886	95.1	4006	2463	108.0
52	3308	1924	96.9	4084	2513	110.0
53	3372	1963	98.6	4163	2564	112.0
54	3435	2001	100.4	4241	2614	113.9
55	3499	2040	102.1	4320	2664	115.9
56	3563	2078	104.0	4398	2714	117.9
57	3626	2117	105.6	4477	2764	119.9
58	3690	2155	107.5	4555	2813	121.9

[1] W. R. Ingalls, "Metallurgy of Zinc and Cadmium."
(a) After burning. An old retort will carry 12–18 per cent. of its weight in zinc.

Dimensions of Zinc Retorts Used in the United States[1]

Place	Cross section	Length, in.	Diameter, in.
Carondolet..........	Circular	....	8
Collinsville..........	Circular	48	8
Friedensville.......	Circular	46	8
Lasalle.............	Circular	54	8¼
Jersey City.........	Circular	54	7
Jersey City.........	Elliptical	54	7×9
Peru..............	Elliptical	....	7½×11
Pulaski............	Elliptical	....	8×10
Pittsburgh.........	Circular	46–50	8
So. Bethlehem......	Elliptical	51	6¾×12¼

[1] W. R. Ingalls, "Metallurgy of Zinc and Cadmium."

Retort Duty.—According to INGALLS, a production of about $4\frac{1}{4}$ tons of spelter per retort per year is a safe estimate.

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TlO	0.006	....	0.006	0.006	....	0.006
FeO	1.896	....	1.896	1.676	....	1.676
MnO	1.332	0.042 (Mn_3O_4)	1.376	0.481	1.591 (Mn_3O_4)	2.072
Fe_2O_3 }	2.900	9.043 }	15.058	2.940	15.928	18.868
Al_2O_3 }		3.115 }		1.191	4.601	5.792
CaO	0.714	0.478	1.192	0.464	1.071	1.535
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The following estimate of electric zinc smelting is given by DORSEY A. LYON and ROBERT M. KEENEY, in a paper before the San Francisco meeting of the A. I. M. E., September, 1915:

Although more progress has been made hitherto in the electric smelting of zinc ores than in that of any of the non-ferrous metals except aluminum, and metals forming ferro-alloys, such as silicon, chromium and tungsten, the process is nevertheless still largely in the experimental stage. There is no plant operating on a commercial scale except the Trollhättan works, taking from 10,000 to 13,000 hp. There are about twenty-four furnaces installed at this plant, each requiring from 400 to 1200 hp. The same company, the Norse Power & Smelting Syndicate, also has a smaller plant near Trolhättan at Sarpsberg, where there are seven small furnaces. One other small commercial plant is in course of erection at Keokuk, Iowa, by the Johnson Electric Smelting Co. It appears that the experiments conducted at Hartford, Conn., for several years have

[1] SCHNABEL'S "Handbook of Metallurgy." The Macmillan Co.

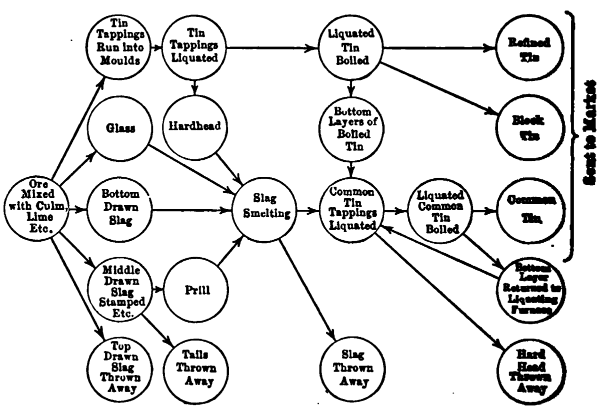
proved successful enough to warrant the installation of a small commercial unit to test the process further. The JOHNSON process and the Trollhättan process are essentially the same. JOHNSON claims to have overcome the problem of condensation of zinc vapor into zinc instead of blue powder.

From the work at Trollhättan and the results of others, it is evident that the difficulty in electric smelting of zinc ores lies almost entirely in the condensation of zinc vapor to a metal, rather than blue powder, under the peculiar conditions of the electric furnace. The electric furnace presents no great difficulties, mechanically or electrically, because all the troubles formerly experienced have been solved in the construction of large pig-iron, steel, carbide and ferro-alloy furnaces. The problem, then, is one of a metallurgical nature, and is caused by the different conditions and greater speed of smelting in the electric furnace, as compared with the combustion retort.

While this problem is difficult, there is no reason why it should not be worked out in time. When it has thus been rendered unnecessary to resmelt a large proportion of blue powder (as at Trollhättan, where 2 tons of blue powder are smelted for each ton of ore treated), it is probable that electric zinc smelting will proceed rapidly in favorable localities. The use of iron as a desulphurizing agent does not seem to have advanced as far as the reduction of oxide with carbon, and it is probable that the latter will keep its present supremacy.

TIN SMELTING

In British practice with ore assaying 65 to 71 per cent., the charges are: Ore, 80 cwt.; culm, 10.4 cwt.; refinery dross, 2.4 cwt. For ore above 71 per cent. increase the culm. This



Flow sheet, tin smelting.[1]

[1] From LOUIS, "Metallurgy of Tin," p. 96.

will give from 4500 to 4800 of tin assaying about 99.5 per cent. of tin, and 2200 to 2500 lb. of rich slag, carrying 35 per cent. of tin. This slag is then smelted as follows: Rich slag, 30 cwt.; rough-metal dross, 12 cwt.; scrap iron, 2.75 cwt.; anthracite, 6 cwt.; coral, 2.4 cwt. It may be noted in operations where tin is on the furnace charge, that it will be carried into either too silicious or too basic a slag, as it forms silicates and stannates and stannites.

Tin Smelting by Electricity

The electric furnace should be appropriate for the smelting of tin ores, since the reduction of tin oxide by carbon requires a very high temperature especially if impurities are to be eliminated. The reduction by carbon produces partly carbon dioxide and partly carbon monoxide, and theoretically would require 665 kw.-hr. per ton of ore. The theoretical amount of energy per ton of ore smelted may be estimated as follows:

Reduction	665 kw.-hr.
Slag	130
Heating tin	65
Radiation	130
Gases	150
Total	1140 kw.-hr.

Experiments on tin smelting, conducted by H. HARDEN in Cornwall, were described in the *Mining Journal* of London, in 1914. The current was a three-phase, alternating, of 50 cycles, 650 to 675 volts. A shaft furnace was used containing 3 electrodes and the formation of a direct arc was avoided. The charge formed a cone around the reaction zone, in which the electrodes burned freely, surrounded by incandescent gases which served as resistance. The three factors, yield of tin, consumption of energy, and losses in slag, are closely interrelated. It is easy to obtain a slag containing only 0.25 per cent. of tin, but the process is not economical, as the consumption is 3000 kw.-hr. per ton of metal. When the slag contains 17 to 19 per cent. of tin the consumption of energy is reduced to 1300 kw.-hr. per ton of metal, but this is not economical. On a recovery of about 96.75 per cent. of the tin in the ores, the consumption was 2200 kw.-hr. per ton of metal. The consumption of electrodes was 12.7 kw. per ton of metal. Arsenides and sulphides of iron were introduced at regular intervals to avoid the formation of hard slag, obtaining a metal containing 98 per cent. of tin from very impure ores. This metal was afterward refined in shaft furnaces containing iron tubes for the injection of air. HARDEN'S conclusions are that the electric process can be advantageously employed in places where the ores are good but not very rich, and where waterfalls can be utilized for supplying the power needed.

NICKEL-COBALT-COPPER SMELTING

In smelting nickel, copper and cobalt together under su conditions as to form a matte and a speiss, it is the gener tendency of the copper to enter the matte in preference to the nickel, and for the nickel to enter it in preference to the cobalt. Some subjoined analyses from SCHNABEL illustrate this very well. The furnace charge (at Altenau) was a leady copper slag, smelted with iron and arsenical pyrites.

	Ni,CO	Cu	Fe	Pb	As	Sb	S
Speiss...	26.77	19.85	15.82	12.14	12.15	10.01	4.57
Matte...	6.10	37.24	20.84	16.10	......	0.47	19.25

The speiss was roasted, then resmelted with heavy spar, arsenical pyrites, copper-refinery slags, and slag from lead-matting giving:

	Ni	Co	Cu	Fe	Pb	As	Sb	S
Speiss...	35.13	10.70	17.18	8.41	6.59	18.65	10.82	2.16
Matte..	4.37	......	37.45	12.68	22.81	tr.	tr.	24.48

MERCURY SMELTING

ANALYSES OF MERCURY SOOT FROM DISTILLATION FURANCES[1]

Mercury	56.30	6.42	3.12
Mercuric sulphide	0.70	2.20	31.10
Mercuric sulphate	18.99	13.07	10.80
Mercurous chloride	2.20	1.80	....
Sulphuric acid	1.10	4.80	....
Magnesia	....	1.10	....
Lime	0.76	1.20	....
Ferric oxide and alumina	tr.	0.80	....
Calcium sulphate	1.04	6.30	....
Basic ferric sulphate	3.24	0.40	....
Soot and tar	33.9	29.40	24.80
Water	4.60	26.50	10.30
Ore residues	11.41	3.80	2.20
Magnesium sulphate	....	....	7.50
Sodium sulphate	....	....	1.24
Ammonium sulphate	....	....	0.54
Ferrous sulphate	....	....	6.02

The mercury is extracted from these residues by pressing, followed by retorting.

[1] SCHNABEL, "Handbook of Metallurgy," Vol. II. The Macmillan Co.

COPPER REFINING

Elimination of Impurities in Reverberatory Refining of Copper[1]

	Cu	Fe	S	Pb	Bi	Sb
Before	98.283	0.062	0.2576	0.5382	0.0045	0.1853
After	....	....	....	0.1100	0.0101	0.1527
Before	....	0.036	0.086	0.029	0.017	0.032
After	99.399	0.004	0.0009	0.006	0.007	0.007
Before	....	0.013	0.088	0.007	0.001	0.129
After	99.475	0.004	0.006	0.004	0.003	0.017

	As	Te	Se	Ni	Ag ounces	Au ounces
Before	0.1709	0.0054	Trace	0.0473	59.91	0.276
After	0.1502	0.0195	Trace	0.0539	61.7	0.27
Before	0.054	0.014	0.010	0.008	....	....
After	0.010	0.003	0.009	0.009	68.17	0.204
After	0.067	0.006	0.005	0.009	....	....
After	0.045	0.003	0.007	0.013	39.893	0.251

Elimination of Impurities in Cupola (Black Copper Smelting)

	Cu	Pb	Bi	Sb	As	Te & Se
Refining furnace slag...	44.47	0.594	0.002	0.2044	0.049	0.0026
Cupola slag...........	....	0.26	0.0	0.0317	0.0033	0.0
Black copper..........	97.7	0.78	0.035	0.0238	0.052	0.0095
Per cent. elimination...	....	4.4	0.0	13.5	6.0	0.0

In refining blister copper to anodes Keller gives the following table of relative slaggability of the various metals:

Cu	Pb	Bi	Sb	As	Te, Se
1	52.1	1.07	5.90	5.07	0.84

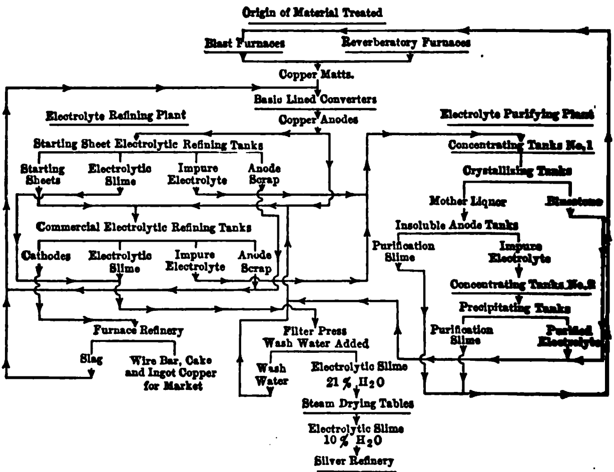
This omits volatilization losses, which would be higher for the last four elements than for the first two ("Mineral Industry," 1901, p. 248).

[1] Private notes.

In the converter, Keller figures that the percentage eliminations of impurities are as follows:

	S	Fe	Zn	Co	Ni	Pb	Bi	Sb	As	Te	Se
Per cent.	99	99	99	99	37	96	97	71	81	40	47

These may serve as the slaggability ratios in the old acid-lined converters.



Flow sheet of Great Falls Electrolytic Plant[1]

Electrolytic Refining Current Losses[2]

320 tanks—22 anodes, 22 cathodes per tank—90 per cent. amp. eff.—2-day cathodes.

	Volts per tank	Volts per 320 tanks	Percentage distribution
Voltage drop—bus bar to anode.	0.044	14.08	7.40
Voltage drop through electrolyte	0.495	158.72	83.36
Voltage drop—cathode to bus bar	0.055	17.60	9.24

[1] W. T. Burns, *Trans. A. I. M. E.*, August, 1913.
[2] R. S. McCaffery, in the "Wisconsin Engineer."

Converter and Furnace-refined Copper Anodes[1]

)MPARISON OF CONVERTER AND REFINED ANODES CAST IN THE SAME MOULDS

	Converter anodes	Refined anodes
ımber of days covered by test	50.0	50.0
ımber of refining tanks employed	48.0	48.0
·erage analyses of anodes:		
Per cent. Cu	98.91	99.27
Per cent. As + Sb	0.072	0.071
Ounces Ag per ton	59.09	61.14
Ounces Au per ton	0.200	0.219
·erage analyses of electrolyte:		
Specific gravity	1.20	1.20
Grams per liter Cu	43.5	43.5
Grams per liter free acid	160.0	160.0
Grams per liter As	11.97	11.97
Grams per liter Sb	0.49	0.49
Grams per liter Fe	10.09	10.09
Grams per liter Cl	0.045	0.045
·erage temperature of electrolyte:		
Inlet of 8-tank cascade, C.°	58.0	58.0
Outlet of 8-tank cascade, C.°	54.0	54.0
.te of circulation of electrolyte, gal. per min.	6.0	6.0
ımber of anodes per tank	20.0	20.0
ımber of cathodes per tank	20.0	20.0
·erage weight per new anode, lb.	525.0	632.0
·erage thickness per new anode, in.	3.0	3.0
stance, center of anode to center of cathode, in.	2.87	2.87
tive cathode surface per tank, sq. ft.	252.0	252.0
·erage amperes per tank	8,387.0	8,387.0
·erage volts for 48 tanks	27.21	28.53
·erage volts per tank	0.567	0.594
·erage kilowatts for 48 tanks	228.2	239.3
·tal copper deposited, lb.	1,103,749	1,148,749
·erage age of cathodes drawn	2½	2½
·erage ampere efficiency of deposit, per cent.	88.3	91.9
·erage amperes per sq. ft. cathode surface	33.3	33.3
·erage lb. copper deposited per kilowatt-hour	4.03	4.00
·erage oz. per ton silver in cathodes	1.25	0.95
·erage per cent. As + Sb in cathodes	0.0043	0.0043
·erage per cent. anode scrap	8.00	5.30
ıalyses of silver slime:		
Per cent. Cu	40.3	18.80
Ounces Ag per ton	6,755.00	14,079.0
Ounces Au per ton	18.34	38.45

The chief disadvantages of converter anodes are: lower ade slimes; higher losses of silver in the cathodes; and higher rcentage of anode scrap. However, MR. W. T. BURNS states at the losses due to these factors are not equal to half the st of reverberatory refining.

Starting-sheet Tank Electrolyte

Specific gravity	1.175
Free H_2SO_4, grams per liter	120.0
Cu, grams per liter	40.0
As, grams per liter	5.0
Sb, grams per liter	0.4
Fe, grams per liter	4.5
Cl, grams per liter	0.04

[1] *Trans. A. I. M. E.*, August, 1913.

Elimination of Impurities in Electrolytic Refining

According to KELLER'S figures about 99.92 per cent. of the copper in the anode goes into solution, the remainder to the slime; from 61 to 78 per cent. of the bismuth goes into the slimes, 30 to 60 per cent. of the antimony (according to conditions worked under), 23 to 38 per cent. of the arsenic; while the silver, gold, selenium, tellurium and lead are quantitatively slimed ("Mineral Industry," 1898, Vol. VII, p. 239). Nickel is slimed if it is present as oxide in the anode copper; dissolved if present as metal. Cobalt, zinc, manganese and iron go into solution.

Work in Insoluble-anode Tanks[1]

REMOVAL OF COPPER, ARSENIC AND ANTIMONY FROM ELECTROLYTE IN INSOLUBLE-ANODE TANKS

(Circulation, 4 liters per minute. Lead anodes, copper cathodes, 9000 amp., 31.8 amp. per square foot)

	Grams per liter					Volts per tank	Temperature, C.°
	Acid	Cu	Fe	As	Sb		
Inlet tank No. 1.....	144	37.060	6.242	3.200	0.463	....	17
Outlet tank No. 1...	184	7.376	6.813	2.240	0.260	2.22	42
Outlet tank No. 2...	194	0.504	7.364	0.400	0.061	2.25	57
Outlet tank No. 3...	208	0.088	7.701	0.056	0.038	2.25	64
Outlet tank No. 4...	216	0.048	7.915	0.028	0.028	2.25	65

CORRECTED ANALYSES[2]

	Grams per liter					Percentage elimination of original amounts			Ampere efficiency, per cent.
	Acid	Cu	Fe	As	Sb	Cu	As	Sb	
Inlet tank No. 1.	144	37.060	6.242	3.200	0.4630	....	....	....	....
Outlet tank No. 1	169	6.760	6.242	2.050	0.2380	81.8	35.9	48.7	71.70
Outlet tank No. 2	165	0.427	6.242	0.339	0.0517	17.1	53.5	40.2	19.50
Outlet tank No. 3	169	0.071	6.242	0.045	0.0308	0.9	9.2	4.7	1.68
Outlet tank No. 4	170	0.038	6.242	0.022	0.0220	0.1	0.7	1.7	0.15
Total and average	.....	....	.....	.....	......	99.9	99.3	95.3	23.26

See p. 552 for some notes on lead, duriron and tantiron as insoluble anodes.

[1] W. T. BURNS, *Trans. A. I. M. E.*, August, 1915.

[2] Calculated to the same value for iron, which is not affected in the insoluble-anode tanks.

COPPER REFINING—ANALYSES OF TYPICAL PRODUCTS

	Converter anodes,[1] per cent.	Electrolyte,[1] per cent.	Wire bar,[1] per cent.	Electrolytic[1] slime per cent.	Electrolyte[2]	Refining-furnace anodes[2]	Slimes flue dust[2]	Casting copper	Blue stone	Blue stone	Slimes flue dust[4]	Anode furnace flue dust	Wire bar flue dust	Crude nickel salt
Copper	99.1300	3.280	99.9500	43.3400	2.51	98.21	2.10	99.34	24.89	25.07	1.70	11.10	31.49	None
Arsenic	0.1183	0.500	0.0016	3.0300	0.5523	0.1492	4.85	0.4237	...	...	5.51	...	...	0.0023
Antimony	0.0534	0.041	0.0015	3.4600	0.0451	0.1716	15.36	0.1092	...	...	17.04	...	...	0.0048
Nickel	0.0420	0.377	0.0006	0.0800	1.23	0.1050	...	0.0795	0.263	0.166	...	...	...	19.27
Cobalt	0.0018	0.016	Trace	0.0060	...	...	...	...	...	...	...	...	...	...
Bismuth	0.0038	0.021	0.0004	0.1100	0.0033	0.0208	...	0.0136	...	...	...	...	...	...
Iron	0.0110	0.600	0.0006	0.3640	0.1456	0.0177	...	0.0026	0.245	0.170	...	3.20	2.80	0.0140
Silver	0.1371	None	0.0030	17.1870	None	0.6050	2.460	Trace	...	...	3.20	0.20	0.01	...
Gold	0.0008	None	Trace	0.1200	None	0.0270	0.003	...	...	...	0.015	0.01	Trace	...
Selenium	0.0090	None	...	1.2000	None	0.0544	7.84	...	...	...	19.52	...	...	...
Tellurium	0.0170	None	...	2.1000	None	0.0720	1.32	...	...	...	1.38	...	...	...
Lead	0.0065	Trace	Trace	0.7600	...	0.0350	...	...	...	...	...	...	...	0.0574
Zinc	0.0035	0.418	0.0001	0.0900	0.0226	0.0250	...	...	...	...	...	...	...	0.2725
Sulphur	0.2610	...	0.0025	13.2100	...	Trace	...	...	...	...	...	7.39	4.19	...
Oxygen	...	...	0.0350	...	...	...	...	...	...	...	...	...	...	...
Silica	...	...	...	0.1770	...	...	...	...	...	...	...	29.48	32.61	...
Chlorine	...	0.0040	...	0.0260	0.0048									
Carbon	...	...	...	0.5900	...	...	...	...	...	...	...	...	...	...
Platinum	...	...	...	0.000166	...	...	...	...	...	...	...	...	...	...
Free sulphuric acid	...	13.0300	...	...	...	...	...	...	...	...	...	...	...	...
Specific gravity	...	1.220	...	...	1.195	...	...	...	...	...	...	...	...	...

[1] First four columns from WILLIS T. BURNS' "The Great Falls Electrolytic Refinery," *Trans. A. I. M. E.*, Aug., 1913.
[2] Eastern practice. [3] Near slimes furnace. [4] Distant from slimes furnace.

Slime from Insoluble-anode Tanks

(Treating electrolyte direct from tank room)

Moisture, per cent.	10.0	As, per cent.....	10.3
Cu, per cent......	55.1	Sb, per cent.....	2.5
SiO_2, per cent.....	1.1	Ni, per cent.....	0.35
FeO, per cent.....	0.4	Zn, per cent.....	0.32
Al_2O_3, per cent....	0.4	Ag, oz. per ton...	3.4
CaO, per cent.....	0.3	Au, oz. per ton...	0.02
S, per cent........	4.1		

Better results are secured from the insoluble-anode tanks Great Falls when the electrolyte from the tank room is boil until it reaches a specific gravity of 48°Bé. It is then crystalliz for 4 days, when the mother liquor then analyzes: acid, 47 Cu, 17.4; As, 20.2; Sb, 1.1; and Fe, 15.2 grams per lit This is then electrolyzed to remove Cu, As and Sb.

Analysis of Insoluble-anode Tank Slime

(Treating mother liquor from crystallizing tanks)

Moisture, per cent	9.66	As, per cent.....	21.48
Cu, per cent......	46.30	Sb, per cent.....	2.28
SiO_2, per cent.....	0.38	Ni, per cent.....	0.35
FeO, per cent.....	1.66	Zn, per cent.....	0.32
Al_2O_3, per cent....	0.4	Ag, oz. per ton..	3.61
CaO, per cent.....	1.08	Au, oz. per ton..	0.03
S, per cent........	5.02		

Materials for Insoluble Anodes

The usual materials for insoluble anodes are platinum, ca bon, iron and hard lead, according to the nature of the ele trolyte. Fused magnetite anodes are also being used, notab at Chuquicamata, Chile, but they are extremely expensi and very brittle. However, when the anodes do not have to handled often, *i.e.*, are not subject to chance of breakage l carelessness, and can be guarded from sudden large changes temperature, they are unquestionably the finest anodes obtai able. In ordinary copper tank-room practice hard-lead anod are usually used in the insoluble-anode tanks. Herewith follo some notes, not hitherto published, furnished by F. R. Pyn assistant superintendent of the United States Metals Refinii Co.'s copper refinery, giving parallel tests on hard lead, du iron, and tantiron electrodes, using them as anodes in v rious electrolytes. The current density was about 20 am per square foot. In a 12 per cent. sulphuric-acid solution tl tantiron lost 0.94 per cent. in 24 hours, the duriron lost 7.: per cent. in 42 hours and the hard lead, 0.69 per cent. in : hours. In regular tank-house electrolyte of approximately per cent. copper, 10 per cent. sulphuric acid, the tantiron lo 1.88 per cent. in 48 hours, the duriron 10 per cent. in 60 hour the hard lead, 0.44 per cent. in 36 hours, and on another test the same solution the hard lead showed a loss of 1.71 per cen

18 hours. This shows that even tantiron and duriron are not of against the violent anodic oxidation and corrosive solu-ıs in the insoluble-anode tanks of a copper refinery.

As against a deposit of 8 to 8.5 lb. of copper per kilowatt-hour ng the multiple process and 10.5 to 11.5 lb. per kilowatt-hour

CHEMICAL ANALYSES OF REFINED COPPER[1]

Element	Lake wire bar	Lake arsenical ingot	Electrolytic wire bar	Best selected English
Cu + Ag	99.900	99.4385	99.9548	99.5510
Cu	99.890	99.4131	99.953	99.530
Ag	0.0096 (2.8 oz.)	0.0254 (7.41 oz.)	0.0018 (0.56 oz.)	0.021 (7.02 oz.)
Pb	2.0031	0.0027	0.0010	0.1331
Bi	0.0000	0.0000	0.0000	0.0000
As	0.0062	0.3183	0.0000	0.0071
Sb	0.0000	0.0000	0.0009	0.0087
Se + Te	0.0020	N. d.	0.0026	0.0066
Fe	0.0028	0.0056	0.0038	0.0044
Ni	0.0090	0.0153	0.0028	0.1112
Zu	0.0000	0.0000	0.0000	0.0000
S	0.0016	0.0071	0.0026	0.0074
O (by diff.)	0.0753	0.2143	0.0315	0.1705
Sn	....	....	....	....
ductivity, annealed	96.49	....	100.45	....
ductivity, hard drawn	93.84	....	97.64	....
erence due to hard drawing	2.65	....	2.81	....
sile strength, lb. per sq. in.	67.590	....	66.300	....
sts in 6 in.	17	....	34.0	....
ngation, per cent	1.03[2]	....	1.04[3]	....
ds, annealed	11.0	....	14.0	....
meter of wire, in.	0.080	....	0.080	....

en using the series process, ordinarily only about 1 lb. per owatt-hour is obtained with insoluble anodes. However, by ng ferrous sulphate as a depolarizer at the anode, a certain ount of aluminum sulphate as a substitute for a diaphragm,

COMPARISON OF SERIES AND MULTIPLE REFINING

	Multiple	Cast-series
npere efficiency	90.0	68.0
ts per tank	0.3	18.0
odes per tank	28.0	120.0
hodes per tank	29.0	120.0
np. per square foot	18.0	16.0
ily deposit per tank	204.0	2040.0
Cu per kilowatt-hour	7.79	11.79

[1] HOFMAN, "Metallurgy of Copper," p. 12.
[2] In 8 in. [3] In 60 in.

and reducing the ferric sulphate formed in the depolarizing, b means of sulphur dioxide, ADDICKS claims to have obtained high as 2.25 lb. per kilowatt-hour. He also claims that wh suitably depolarized, carbon anodes will stand up in a sulpha electrolyte. ("Electrolysis of Copper Sulphate Liquors, usi Carbon Anodes," joint meeting A. I. M. E. and A. E. S., Sa Francisco, Calif., Sept. 17, 1915.)

Electrolytic Lead Refining.—In a refinery operating und commercial conditions the ampere efficiency in lead depositi was 88.5 per cent. with a deposit of 20 lb. per kilowatt-hou The current density used was 16.7 amp. per square foot. Anod were spaced $4\frac{1}{2}$ in. from center to center. Starting sheets we cast by allowing molten lead to flow down an inclined cast-ir plate. Electrolytic lead refining must be made to pay throu its byproducts, particularly bismuth, and it seems questionab whether it can be adapted to a low-bismuth bullion.

TYPICAL ELECTROLYTIC LEAD REFINERY MATERIALS

	Pb, per cent.	Ag, oz. per ton	Au, oz. per ton	Bi, per cent.	Cu, per cent.	As, per cent.	Sb, per cent.	Te, per cent
Anodes.....	97.79	139.9	1.52	0.21	0.065	0.85	0.52	0.01
Slimes......	13.52	4949.2	40.69	4.81	1.45	17.36	22.75	0.45
Electrolyte.	8.32	....	.....	0.00058	0.00049	0.0008	0.012	....
Refined lead	.....	0.29	Tr.	0.0024	0.001	Tr.	0.0066	....
Slag, slimes smelting...	37.50	313.0	0.72	1.68	2.65	6.75	22.92	....

Electrolytic Production of Metals

Aluminum—from fused cryolite bath containing Al_2O_3 solution (cryolite 36 per cent.; AlF_3 44; CaF_2 20). The specif gravity of a saturated solution of Al_2O_3 in cryolite is 2.35, that molten aluminum is 2.54. The bath must be fluid at 900° 950°C. Cryolite melts at 1000°C., but with 10 per cent. Al_2O present it is 930°C., and with 20 per cent. 880°C.; 25 per cen saturates the solution. The current density is about 700 am per square foot of cathode section, potential (theoretical, 2 volts) 7.5–8.5 volts. Anodes are carbon blocks, cathode th carbon lining of the furnace. Power consumption 1400 e.h. per metric ton of metal per 24 hours. Also prepared by electr lyzing a double sulphide of aluminum and sodium. Potenti about 5 volts. The alumina for electrolysis should carry minimum of 98 per cent. Al_2O_3.

[1] These slimes were largely produced from the anodes just above.
[2] Carries also 11.78 per cent. H_2SiF_6; 0.36 per cent. HF; 0.28 per cen Zn; 0.44 per cent Sn

Some Typical Bauxites[1]

	New South Wales	Italian	French	French	German
Al_2O_3.....	42.20	47.44–57.00	78.10	43.20	55.61
Fe_2O_3....	28.91	25.98–36.77	1.02	7.25	7.17
SiO_2......	0.16	2.33– 4.06	5.78	34.40	4.42
TiO_2.....	4.75	1.17– 2.86	....	....	....
CaO.....	0.28	....	....	....	....
MgO.....	0.37	....	....	....	....
KNaO....	0.17	....	....	....	....
Volatile...	23.45	....	15.10	15.15	32.33

Antimony—may be recovered by electrolysis from the sulphantimonite. The anodes are lead plates, the cathodes and tanks are iron. Current density is 10 to 15 amp. per square foot at start, later 4 to 5 amp. per square foot. The voltage is about 2. The metal is always contaminated with iron when produced in this way. Betts also proposes electrolysis of the fluoride in solution carrying an excess of hydrofluoric acid.

Beryllium—from the fused double fluoride of sodium and beryllium.

Bismuth—is refined electrolytically in $BiCl_3$ solution carrying an excess of free hydrochloric acid. Current density, 15–30 amp. per square foot. Anodes, argentiferous and auriferous bismuth; cathodes, pure bismuth; porcelain tanks.

Cadmium—obtained by the electrolysis of $CdCl_2$ or $CdSO_4$ solutions. Current density, 6 to 15 amp. per square foot; e.m.f.; 0.045 volts. Cathodes are cadmium sheets, anodes are of crude cadmium.

Calcium—from fused calcium chloride or iodide. Current density must exceed 500,000 amp. per square meter. Electrolyte near cathode must be at lowest possible temperature. Cell resistance, 12 volts.

Cerium—from the fused chloride, which is traversed by an alternating current to keep it fused and decomposed by direct current.

Chromium—according to Borchers, may be produced by electrolysis of a $CrCl_2$ solution containing 13–14 oz. of chromium per gallon. The anodes are carbon, the cathodes platinum foil. The current density must be from 85 to 170 amp. per square foot. At 70 amp. per square foot the metal contains perceptible amounts of CrO, and with 8 amp. per square foot, only CrO is deposited. The temperature must not exceed 122°F. G. Glaser has compiled the following table regarding the behavior of chromium during electrolysis:

[1] Schnabel, "Handbook of Metallurgy." The Macmillan Co.

Current density, amp. per sq. ft.	Deposit	Current efficiency
8.36	Chromo-chromic oxide	....
16.7	At first metal, then chromo-chromic oxide	....
33.4	Metal, mixed with chromo-chromic oxide	....
41.7	Thin metallic layer, on which oxide afterward deposits	5.4
66.8	Metal, with a small quantity of oxide	23.4
84.5	Pure metal	38.4
127.3	Pure metal, with a growth of crystals	38.0
169.0	Pure metal, for the most part crystallized	38.6

The effect of solution concentration was also studied:

Grams Cr per liter of solution	Deposit	Current efficiency
210	Metallic powder, mixed with chloride of chromium	....
184	Same	....
158	Pure metal	56.6
135	Pure metal	49.0
105	Pure metal	38.4
79	At first metal, then chromo-chromic oxide	....
53	Chromo-chromic oxide and hydrogen	....
26	Trace of chromo-chromic oxide, brisk evolution of hydrogen	....

Copper—obtained by the electrolysis of copper-sulphate solutions carrying free sulphuric acid, using copper cathodes and anodes. Current density about 12 to 15 amp. per square foot, e.m.f. 0.34 to 0.44 volt. Temperature of solution about 114°F. Ag, Au, Pb, Se, Te go quantitatively to the slime; Bi, As, and Sb, chiefly to the slime; Fe Ni, Co into solution, except the nickel be present in the anode as NiO.

Gold[1]—from gold-chloride solution carrying 25–30 oz. of gold and 25–30 oz. free HCl (sp. gr. 1.19) per cubic foot. The anode is the unrefined gold, the cathode is a pure sheet. If anodes carry lead, some H_2SO_4 is added. Current density about 100 amp. per square foot, potential 1 volt, temperature 60–70°C. Tanks—stone or porcelain. (WOHLWILL process.) Pt stays in the electrolyte, Ag slimes as chloride.

Iron—may be obtained by electrolysis of the sulphate. Anodes are pig iron, the cathodes are pure metal. Current density about 110 amp. per square meter, electrolyte contains 10 per cent. $FeSO_4 \cdot 7H_2O$ and 5 per cent. $(NH_4)_2SO_4$. Temperature carried at about 30°C. Voltage drop across tank about 0.3 to 0.9 volts. This, however, gives a metal carrying a trace of sulphur. Theoretically the chloride should furnish an electrolyte free from this objection, practically chloride electrolytes are awkward to work with. There is a great deal of occluded hydrogen in the metal as precipitated.

[1] From W. BORCHER'S "Metallurgy."

Lead—can be produced by electrolysis in a solution of lead fluosilicate carrying free hydrofluosilicic acid and a little gelatin. Anodes, base bullion; cathodes, pure lead sheets. Temperature of solution, about 87°F. cathode density, 10–12 amp. per square foot.; potential, about 0.3 volts; tank, wooden.

Lithium—from fused mixtures of LiCl with an alkaline-earth chloride. From a solution of lithium chloride in pyridine. 20–30 amp. per square centimeter, 14 volts.

Magnesium—from fused magnesium chloride, from fused K-Mg or Na-Mg chlorides. Current density, 1000 amp. per square meter; cell voltage, 1 to 8; anode, carbon in porcelain envelope. Do not raise temperature of bath much above melting point of the magnesium.

Potassium—from fused mixtures of KCl with an alkaline-earth chloride. General process same as sodium.

Silver—(MOEBIUS and THUM processes) recovered by electrolysis of a nitrate solution carrying about 0.1 per cent. free HNO_3, 5.0 per cent. Ag, and some copper. The cathode is either silver (MOEBIUS process), or carbon (THUM process). The anode is the doré. The current density is 30–40 amp. per square foot; the e.m.f. is 1.4–1.5 volts; the tanks are usually porcelain. The Cu in the anodes dissolves; Pt and Au stay in the slime.

SOLUBILITY OF SILVER CHLORIDE[1]

Salt	Strength of solution, per cent.	Temperature, deg. C.	Silver chloride dissolved per liter, grams	Silver per liter, grams
KCl	24.95	19.6	0.914	0.688
NaCl	25.96	19.6	1.270	0.956
NH_4Cl	28.45	30	3.673	2.764
$CaCl_2$	41.26	30	8.350	6.283
$BaCl_2$	27.32	30	0.741	0.558
$MgCl_2$	36.35	30	7.095	5.339
$FeCl_2$	30.70	20	2.395	1.802
$FeCl_3$	37.48	21.4	0.085	0.064
$MnCl_2$	43.85	30	2.958	2.226
$ZnCl_2$	53.34	30	0.215	0.162
$CuCl_2$	44.48	30	0.833	0.627
$PbCl_2$	0.99	30	....	....

The above table is by H. C. HAHN and W. M. CURTIS. According to VOGEL and BERNHART, the solubilities in grams of silver chloride per liter of solution are as follows: KCl, 0.472; NaCl, 0.950; NH_4Cl, 1.575; $CaCl_2$, 0.930; $BaCl_2$, 0.143; $SrCl_2$, 0.884; $MgCl_2$, 1.710. They also state that it is insoluble in the chlorides of tin, mercury, copper, zinc, cadmium, nickel and cobalt. But some unpleasant experiences of my own

[1] SCHNABEL'S "Handbook of Metallurgy," Vol. I. The Macmillan Co.

convince me that it is highly soluble in a mixture of cuprous and cupric chlorides.

Sodium—from fused sodium hydroxide—CASTNER process—Iron anode, carbon cathode. From fused sodium nitrate—DARLING'S process—Iron melting vessel serving as anode. Magnesia diaphragm, carbon cathode. Cell resistance 15 volts. From fused sodium chloride. Current density over 5000 amp. per square meter.

Strontium—from fused strontium chloride. General conditions like those of calcium production.

Tin—the electrolysis of tin commercially is confined to the detinning of old tin-plate, chiefly by the caustic-soda process. The cathodes are iron, the anodes are the tin scrap, packed in wooden baskets. Electrolyte contains about 9 per cent. NaOH, which is recausticized from time to time by $Ca(OH)_2$. The tank potential is about 1.5 volts, the current density 8–12 amp. per square foot and the temperature 160°F. and up. Alkaline sulpho-stannates have also been proposed as electrolytes.

Uranium—from fused uranium-sodium chloride; cell resistance, 8 to 10 volts.

Zinc—The Brunner, Mond & Co. works at Winnington is said to operate as follows: The electrolyte is $ZnCl_2$ with 0.08 to 0.12 per cent. free HCl, the cathodes are rotating zinc plates, and the anodes are carbon. The current density is 10 amp. per square foot and the e.m.f. of the cell is 3.3. to 3.8 volts. The apparatus is complicated, as there must be piping for carrying off the chlorine generated, which is then used for making bleaching-powder. The solution tends to become basic after prolonged electrolysis and additional acid must be added.

Since the outbreak of the war a great deal has been done to solve the general problem of the electrolytic production of zinc. The following is understood to be the outcome of the experiments, but accurate data are hard to obtain. At Anaconda, Mont., and Trail, B. C., the ore is leached with the spent electrolyte which contains free sulphuric acid until almost neutral. The solution is then freed from impurities with zinc oxide and electrolyzed, using lead anodes. The process appears to be what every experimenter has tried for some years, and success is, apparently, a matter of close attention to details of current density, concentration, etc.

In the process as conducted by Keating at Bully Hill, Calif., lime is used to precipitate zinc hydroxide and calcium sulphate from the solution of the zinc sulphate. This precipitate is suspended in the zinc sulphate liquor of the electrolytic cell and as fast as sulphuric acid forms it is neutralized by the zinc hydrate.

In the Mammoth Copper Co.'s experiments at Palo Alto., Calif., a sponge-lead cathode is used, the sulphuric acid formed by electrolysis forming lead sulphate, which can be decomposed later by reversing the current. The material used is said to be the result of leaching the baghouse dusts with sulphuric acid.

Recovery of Radium from the Olary Ores

ecause of the general interest in the extraction of radium the wing excerpts are given from S. RADCLIFF's description ne recovery of radium from the Olary (Australia) ores at the ium Hill Co.'s plant at Sydney, N. S. W. (*Min. and Eng. ew*, Oct. 5, 1914).

he ore is dry crushed at the mine to pass a sieve of 20 holes e linear inch, and is then concentrated magnetically; the entrates, amounting to about 30 per cent. of the ore crushed, g forwarded to Sydney for treatment.

he concentrates have the composition: CaO, 0.55 per cent.; , 0.16; Fe_2O_3, 17.4; FeO, 16.9; MnO, tr.; thorium, cerium, hanum and didymium oxides, 3.27; Cr_2O_3, 0.85, U_3O_8, V_2O_5, 0.86; TiO_2, 45.85 per cent.; SiO_2, 12.70.

s the concentrates are insoluble in acids, a fusion process is ssary to effect the initial decomposition. The concentrates mixed with three times their weight of salt cake (acid sul- e of soda) and fused in a reverberatory furnace of sufficient city to take 500 kilos of concentrates and 1500 of salt cake single charge. Three charges can be put through in 24 s. The fused product, crushed to 8 mesh, is fed, in small unts at a time, into wooden vats filled with agitators. Cold r is fed continuously into the vats at the bottom and an flow is provided near the top. By suitably adjusting the litions, it is possible to separate out on the bottoms of the a considerable amount of comparatively coarse material h is almost free from radium and uranium. The turbid id overflowing carries in suspension the radium, lead and um as sulphates, together with a considerable amount of y divided silica; while in solution we have the uranium earths, and part of the iron and acid earths contained in the

he coarse residues are removed from the vats daily, re- hed to free them from any undissolved fused product and to the dump.

he overflow from the dissolving vats is pumped to large -lined settling tanks and allowed to stand all night. The mes" settle completely in 12 hours, and the clear liquid is vn off daily and treated for the recovery of the uranium. slimes which amount, when dried, to approximately 10 cent. of the weight of the concentrates, are collected weekly treated for the recovery of the radium as described below.

he further steps in the treatment process may conveniently lescribed under two heads:

ı) The recovery of the uranium.
) The recovery of the radium.

Recovery of the Uranium

he clear solution containing the uranium and much of the and other bases in the concentrates, together with a large unt of sodium salts, is fed into series of vats containing a sured excess of a mixture of carbonate and bicarbonate of

soda; and heated and agitated by means of steam jets. The iron, with most of the other bases present, is precipitated, while the uranium goes into solution together with some of the rare earths. The bulky iron precipitate is separated partly by settlement and partly by means of vacuum filters. It is difficult to handle and cannot be washed effectually; a portion of the uranium is therefore unavoidably discarded along with this precipitate. The uranium solution is made just acid with sulphuric acid, heated and the carbon dioxide expelled by a brisk current of air. The uranium is then precipitated by the addition of ammonia. The ammonium uranate is thickened somewhat in conical settling tanks and then further thickened to a pulp in a hydro-extractor. This pulp is dried and dehydrated in large muffles. The dehydrated product is broken up and washed repeatedly with hot water. This treatment removes the bulk of the sodium salts, and a product is obtained which on drying contains about 75 per cent. of U_3O_8. An analysis of this, together with that of the iron precipitate, is given below. Prior to analysis the iron hydroxide was twice dissolved and reprecipitated with ammonia to free it from the large amount of sodium salts present. The washed precipitate was dried, ignited and analyzed.

	Uranium product	Iron precipitate
Insoluble matter	3.0	....
Titanium dioxide	....	8.11
Ferric oxide	9.41	74.65
Uranoso-uranic oxide	16.6	2.7
Rare earths	1.57	7.36
Lead oxide	0.51	....
Vanadic oxide	....	1.2
Chromium oxide	....	5.81
Sodium salts	8.21	....

Recovery of the Radium

The thickened insoluble residue or slime from the settling tank is mixed with half its dry weight of strong sulphuric acid and allowed to stand for several days. It is then washed, first by decantation and then on a vacuum filter, till the washings give only a very slight precipitate with barium chloride. The acid treatment and washing reduces the bulk of the slime considerably, removing large amounts of acid earths and iron salts. The washed slime in quantities of about 200 kilos, dry weight, is then boiled in a large steel boiler under pressure with an excess of a 20 per cent. solution of sodium car onate for two days, the solution being replaced once during the boiling. This treatment dissolves a large amount of silica, and converts much of the lead, radium, and barium sulphates to carbonates. The slime is then washed till the wash water gives no reaction for

sulphates; this takes 2 days for each lot of 200 kilos. The washed slime is then fed into a warm dilute solution of hydrochloric acid, agitated for a couple of hours, and allowed to settle all night. The clear solution is siphoned off and the lead, barium, and radium precipitated as sulphates. After washing once by decantation, the slime is again treated as above described. Two treatments suffice to extract most of the radium, but the slime is reserved for a further treatment, if necessary. The plant as at present arranged can treat the slime from 10 tons of concentrates per week. The weekly yield of crude sulphate is about 12 kilos.

A number of experiments, both in the laboratory and on the working scale were made to see if the sulphates in the slime could be reduced by heating the material with carbonaceous substances, or else in a current of some reducing gas, but the results so far have not been encouraging.

The treatment of the crude sulphate is now carried out as follows, not as in the paper read by the author before the Royal Society of New South Wales in 1913: The crude sulphate is dried and fused with three times its weight of caustic soda in an iron pot. The melt is poured, cooled, and digested with hot water. Most of the lead goes into solution. The insoluble residue is washed till free from soluble sulphates, and then digested in a rotating boiler under a steam pressure of about 60 lb. This converts the bulk of the sulphates of barium, radium and lead to carbonates. The carbonates are well washed on a filter and dissolved in hydrochloric acid. The solution is taken to dryness to remove any colloidal silica, and the residue is taken up with water and a little HCl. In addition to barium and radium chlorides, small amounts of iron and lead chlorides, together with considerable quantities of barium, lanthanum, didymium, and thorium chlorides are present. This solution is now saturated with hydrogen chloride gas; the barium and radium are precipitated quantitatively as chlorides, almost free from the other substances present. The chlorides are filtered off, dried, dissolved in water, and purified from the small amounts of second and third group elements in the ordinary way. They are finally precipitated as carbonates by means of pure Na_2CO_3, and the carbonates dissolved in HCl. This solution is now ready for fractional crystallization for the recovery of the radium.

The economic success of the process depends on the fact that it is possible to decompose the uranium minerals without bringing the whole ore complex into solution, and that comparatively small amounts of reagents are required to effect this. The tailings sent to the dump, amounting to about 50 per cent. of the material smelted, are almost free from radium and uranium, and appear to consist mainly of unaltered rutile. The radioactive slimes amount to about 1 ton from every 10 tons of concentrates, and are one-fifth of the weight of the tailings. As the alpha ray activity of the slimes is thirty times that of the tailings, it appears that the slimes carry over 80 per cent. of the

radium originally present in the concentrates. That is, the initial fusion of the concentrates enables a great concentration of the radium to be made by mechanical means before continuing the chemical treatment.

The rare earths in the concentrates distribute themselves in the course of the iron hydroxides carrying 7.36 per cent. rare earths, the uranium product containing 1.57 per cent. and the crude sulphates. The rare earths extracted from the iron hydroxide precipitate are only very feebly radioactive. The activity does not increase with time, and is due to the presence of 0.06 per cent. of thorium oxide, with its attendant ionium. The earths extracted from the uranium product are also only very feebly active. The rare earths carried down with the crude sulphate contain a considerable proportion of the thorium in the ore, and appear also to carry most of the actinium. This is to be expected, as it is well known that actinium can be extracted from a solution by precipitating barium sulphate in it. A thorium-ionium preparation worked up from the earths in the crude sulphate has an activity several hundred times as great as that of U_3O_8.

The rare-earth mixture, containing about 3 per cent. of rare earths in addition to the constituents enumerated, is fused in an iron crucible with excess of sodium hydroxide containing some sodium carbonate, the melt extracted repeatedly with hot water, the insoluble residue digested with excess of sodium carbonate under a steam pressure of 90 lb., the carbonate residue washed, treated with dilute hydrochloric acid, the solution evaporated to dryness, the residue treated with water, the silica filtered off, and the solution saturated with hydrochloric acid gas (to precipitate the radium and barium) and filtered. The filtrate, containing the actiniferous rare earths, is evaporated to dryness and the residue further treated to separate actinium. *Ionum* appears to be chemically inseparable from thorium, so that by extracting and purifying the latter by any of the well-known methods an active ionium product is obtained.

DUST AND FUME CONDENSATION

The problem of dust catching is one of reducing the speed of the gas sufficiently. JAMES DOUGLAS, in writing of the Copper Queen, says that all true dust would settle from a velocity of 2½ ft. per second in a chamber 125 ft. long, which rate of settlement can be materially increased by wire screens placed across the direction of flow. Later it was understood that the rate adopted was 5 ft. per second. Hence dust settlement reduces itself to a question of large chambers and of temperature reduction, which reduces volume and hence speed. The reduction of temperature can best be achieved by thin-walled steel flues—often, as at Mammoth, by passing the gas through a great number of parallel steel pipes. These pipes may or may not be cooled by a water spray. Another method is to make the top of a brick out of a series of cast-iron pans which are set step-fashion,

so that each overflows into the next, the feed being just sufficient to equal the combined evaporation from all the pans.

The use of baffles and tortuous windings in the flues has largely been given up, as it is usually conceded that these act more as stirrers than settlers. However, settlement is helped by plates hung so that they are parallel to the travel of the gas (FREUDENBERG plates), or by wires across the travel (ROESING'S wires).

A stack is of practically no value as a dust settler.. It may be needed to give the necessary draft through the flues, or to discharge the gas so high that it will be diluted enough not to be unendurable by the time it reaches the ground, but that is about all. When a dust particle starts up a stack it usually emerges on top. The WISLICENUS stack consists of a large number of radial openings near the top of the stack. The wind enters through these and quickly dilutes the effluent.

The ferrous metallurgist uses the centrifugal gas washer (a test of a THIESSEN washer is given in the succeeding pages) but it seems doubtful whether they would have any effect on the lead- or copper-smelter's fume.

For fume condensation the most successful treatment seems to be the COTTRELL system of electrostatic discharge, described at more length below, filtration through bags, or precipitation by thoroughly atomized water (SCHÜTTE-KOERTING system). Scrubbers in which the gas is allowed to bubble through water amount to very little, although their efficiency can be raised, usually, by oils or acids in the water. Figures on baghouse work are given on p. 565. While a baghouse should pay in lead smelting or on silver furnaces, it probably does it only indirectly in copper work—by keeping the smoke farmers quiet.

Gas control must be by chemical means, except that SO_3 is very easily condensed by the COTTRELL system. Sulphur dioxide and trioxide are controlled completely at the Ashio mines, Japan, by passing all the effluent gases through lime water. The SPRAGUE system adds zinc oxide to the flue gases and filters out the zinc salts in the baghouse. The HALL process aims to reduce the sulphur oxides to sulphur as formed in the furnaces using hydrocarbon vapors as the reducing agent. YOUNG'S thiogen process aims at the reduction of the sulphur vapors in the flues by hydrocarbon gases.

Electrostatic Precipitation (Cottrell Process)

This is best performed in tubes in which the tube forms one electrode and a wire placed concentrically with it forms the other. The discharge should not be one produced by an alternating current, but should be a silent discharge with the wire preferably the negative anode. The breakdown voltage with most smoke is about 32,000. The presence of fine points due to hardened deposits, kinks in the wire, rough spots, etc., tends to localize the discharges from the wire, and even though there be many such points, the cleaning action of such discharges is

much below that of a uniform field around a straight wire (A. F. NESBIT, "*Trans. A. I. E. E.*," Third Midwinter Convention, Feb. 17 to 19, 1915).

At the Hooker Electrochemical Co.'s Plant 30,000 cu. ft. of gas per minute is treated with a power consumption of 3 to 5 kw. At the Garfield, Utah, smeltery 200,000 cu. ft. of gas per minute is treated with an expenditure of 50 kw. The electrode spacing is 2½ in. and the potential is 50,000 volts. At Tooele, Utah, 20,000 cu. ft. of gas per minute requires less than 5 kw. Each of the two units contains 48 pipes 12 in. in diameter by 15 ft. long.

A full review and complete bibliography of this process is given in in the Eng. and Min. Journ. of Feb. 12, 1916.

Thiogen Process

The thiogen process was devised by S. W. YOUNG of Stanford University, in an attempt to eliminate sulphur gases from smeltery smoke. The process contemplates passing a mixture of the sulphur-bearing gases and a hydrocarbon reducing agent of the ethylene series over a catalyst of calcium sulphide. The reactions are:

$$CaS + SO_2 = 2CaSO_3 + 3S$$
$$2CaSO_3 + C_2H_4 = 4CaS + 2CO_2 + 2H_2O.$$

In practice, when a mixture of sulphur dioxide and hydrocarbon vapor pass together over a mixture of calcium sulphide and calcium sulphite, the reactions proceed simultaneously. The hydrocarbon gas is generated from fuel oil. The process has been tried at the Penn Smelting Works, Campo Seco, Cal., but the catalyst poisons easily and it does not appear that it is yet a commercial process. (See Eng. and Min. Journ., Feb. 15, 1913.)

Hall Process

An invention of E. J. HALL, by which sulphur-bearing gases were to be treated immediately after their formation with a reducing gas containing some hydrocarbons. Elemental sulphur was to be set free, which was to be recovered in a centrifugal scrubber. The process was tried at the Balaklala smeltery in California, but is understood to have given trouble through the formation of allyl compounds that rendered the neighborhood extremely offensive, and through the fact that the washers did not do what was expected of them. (See Eng. and Min. Journ., July 5, 1913, for a fuller account of the theory of the process.)

Bag-house Data

Some data were given by ANTON EILERS, before the International Congress of Applied Chemistry in 1912, concerning bag houses of the American Smelting & Refining Co. The Murray, Utah, plant treats furnace charges low in lead (10–12 per cent.) and the precious metals. They are wet and carry up to 4 per cent. of sulphur. Its total cost was $127,195 including the cost of 4,032 cotton bags and the distributing flue, etc.

uilding was 216½ × 90½ ft., and was 51½ ft. to the roof s. Stacks carried the fumes out of the building and it ecessary to place a lead-lined pan at a sufficient distance the stack not to interfere with the draft, to catch the con- l moisture dripping from the stack sides, which otherwise on and eats away the bags. The bags are 18 in. in diam- nd 30 ft. long, shaken from outside. The average life ton bags costing $2.136 a piece, was 17 months, 11 days. were replaced by woolen bags from the Buell Mfg. Co., seph, Mo., costing $4.7185 apiece, which it is estimated years. Other bags were bought from the Laporte n Mills, Laporte, Ind., at a cost of $4.784. There are 2 sq. ft. of filtering surface for filtering 165,000 cu. ft. per minute, but if one compartment was down, there were ı. ft. of filtering surface per cubic foot per minute. If 4 in. of fume is allowed to accumulate in the cellars under gs, spontaneous combustion begins. Therefore, when the of any compartment contains 24 in. of dust, it is damp- ff from the bags, hot coals thrown in on the dust, and the ntered by its own combustion. In this Murray bag house llowing percentages of the metals charged in the furnaces recovered: Lead, 1.269 per cent.; silver, 0.063 per cent.;).049 per cent.; and copper, 0.0118 per cent. The oper- cost in 4⅔ years was $76,853; treatment charge on the ial recovered was $69,290, while the value of the metals red was $152,691, showing an apparent gain of $6,547, proper interest and amortization charges be placed against re is a net loss of $58,746. These figures show that, tak- ie immediate financial outcome only, bag houses are not ible in lead-smelting works, except where it is an object p smoke-suits.

Omaha Plant

s plant treats gases from converters treating leady copper s; from blast furnaces treating rich charges; and from xide furnaces. The following facts are given for the con- bag house. The secret of long life for the bags is said horough cooling of the gases before admission, and a good m over the bags, drawing off the exhaust gases rapidly. onverter bag house has 68,000 cu. ft. in the flue; 67,000 in the cellar; 174,000 cu. ft. in the bag chamber; has 940 18 in. × 28 ft. long, having 124,000 sq. ft. of filtering area; the gases from converting about 45 tons of blister, or 5,200,000 cu. ft. of gas which usually passes in 15 hr. out 24. The gas temperature at the bag house is 152°F. ag house showed a profit of $98,712 per year on a $42,000

ie other miscellaneous bag-house data have been collected ows:

vashed-wool bags have been found to be the best for ıg purposes because they last much longer than any other Unwashed wool is wool which has not had the animal scoured out.

The method of neutralizing sulphurous gases at the United States lead smeltery at Bingham Junction is to pass the gases through steel flues exposed to the atmosphere in order to get cooling effect; then to add powdered lime to combine to form calcium sulphate. Zinc oxide is also very valuable for neutralizing these gases, but it is expensive. However, since the works have zinc concentrates to treat, these will be mixed with crushed coal or coke, and roasted in furnaces near the flues. The zinc-oxide fumes resulting will be conducted into the main flues after the lime has been added, about 100 ft. further on, so that the lime shall have had time to act. A considerable velocity of gases is required in order to keep the lime in suspension, 2200 ft. per minute, which was the velocity of the copper blast-furnace gases in the flues.

The gases should travel at least 100 ft. after the neutralizing agents have been put in, in order to give them time to act.

Apart from their greater resistance to sulphuric acid, sulphuric anhydride, and selenium dioxide, wool bags are superior to cotton for filtering purposes because of the fine hairs lying on the surface, which arrest all the finest possible particles of the fume before they reach the actual pores of the filtering medium.

The bags at the United States lead plant are 34 ft. 6 in. long × 18 in. in diameter. When tied in place they give a net filtering area 31 ft. × 18 in. diameter, equal to 141 sq. ft. of filtering surface per bag. One sq. ft. of bag filter cloth is allowed for 0.7 cu. ft. of gas at 0°C. These bags weigh 7 to 8 lb. each and cost 45 cts. per linear yard. The freight on bags per pound is 2½ cts. and the hanging cost is estimated at 15 cts. per bag. This makes the total cost per bag in place $5.50. The mechanical shaking device installed in this bag house costs at the rate of $2 per bag.

In the Mammoth bag-house experiments, 1 sq. ft. of filter cloth filtered 0.75 cu. ft. of gas at 0°C. under $\frac{1}{16}$- to $\frac{1}{8}$-in. water pressure. There was no apparent deterioration of bags at 50° to 100°C. When temperature falls below 45° the bags become damp and permit the fume to escape. In dry weather, the temperature can be as low as 25°C. and the bags filter all right. The cotton bags used were of 50 mesh and the wool bags of 20 mesh.

At the United States lead bag house the ideal temperature for lead blast-furnace gases is considered 70°F., and must not exceed 90°. The ideal temperature for roaster gases is 100° and must not exceed 120°F.

At the United States lead bag house the blast-furnace bag dust is high in arsenic. This dust ignites of its own accord in the dust chamber basement and sinters to a sort of clinker which is treated in the arsenic plant. This clinker contains on an average 22 per cent. arsenic and 32 per cent. lead. This product goes to the Brunton furnace, 20 ft. diameter × 4 ft. high, encased in brick, fired with coke, and with the hearth revolving once in about 9 min. The arsenic volatilizes and passes off as As_2O_3. The lead sinters and is worked off the

hearth into hoppers by rabbles. This averages 40 per cent. lead and 9 per cent. arsenic. The As_2O_3 fume discharges into brick settling chambers 200 × 20 × 10 ft. high for the first 50 ft., and 8 ft. high the rest of the length. At intervals of 8 ft. in this chamber are baffle walls to make the gases zigzag and deposit acid on the walls. The product from this chamber averages 97 to 99 per cent. arsenic and is further refined in a reverberatory furnace 25 ft. × 15 ft. × 6 ft., coke fired. This chamber is kept at 500° at 30 ft., 200° at 100 ft., and 120° at 175 ft. from the furnace. If the end chamber gets too hot the acid goes off and is lost. This product is crystalline and has to be ground for the market. It assays 99.87 per cent. pure and is much better than the foreign article.

In installing any bag house the quantity of gases and the temperatures will be known. It is required to determine the amount of cooling surface necessary to reduce this temperature to one which would not injure the bags, and then to determine the number of bags required to filter this amount of gas. The length of the cooling pipes is more or less fixed by the contour of the ground, and the available sites for the bag house. The sizes of the pipes are determined by the quantity of the gas flowing.

Experiments in radiation and conduction through No. 8 steel plate show that the rate of heat transmission is equal to 0.042 B.t.u. per minute per square foot of cooling surface per degree difference between temperature of gas and external air. The weight of this gas may be taken at 0.08 lb. per cubic feet at 0°C., and its specific heat at 0.2375.

A typical baghouse fume is Pb, 52.5 per cent.; Zn, 3; S, 5.4; As, 14.2; Sb, 1.6.

Chimneys[1]

The velocity of discharge of a gas from a chimney is as follows:

$$V = \sqrt{2gh\left(1 - \frac{t'}{t''}\right)}$$

where V = Velocity in feet per second.
g = Acceleration due to gravity.
h = Height of chimney in feet.
t' = Absolute temperature of external air.
t'' = Absolute temperature of the hot gas.

Since the velocity varies as the square root of the height, high chimneys do not pay. Indefinite increase in temperature of the exhaust gas is not an advantage, either, for although the velocity increases with increased temperature, the increase in volume offsets this. The maximum results are obtained at 273°C. over outside air.

Draught power of a chimney in inches of water is:

$$d = h\left(\frac{7.64}{t'} - \frac{7.95}{t''}\right)$$

[1] W. R. INGALLS, "Metallurgy of Zinc and Cadmium."

Copper Leaching

In general, leaching processes fall into 12 distinct groups: (1) Oxidation of sulphides in the ore with formation of water-soluble sulphates. This may be slow, going on at ordinary temperatures; or a quick sulphatizing roast. This latter, in turn, may be either an oxidation of sulphides already present in the ore, or with addition of pyrite material, such as was tried in the Shannon Copper Co.'s experiments. However, owing to the formation of basic compounds, the products of the sulphatizing roast must ordinarily be treated with dilute sulphuric-acid solution, so that this process grades into: (2) Leaching of oxidized ores or calcined sulphides with sulphuric acid, in which category come the successful operations of the Anaconda Copper Mining Co., the Chile Exploration Co.'s plant at Chuquicamata, the New Cornelia Copper Co. at Ajo, Ariz., the Arizona Copper Co.'s leaching plant at Clifton, and the Butte-Duluth and Steptoe plants. Somewhat akin to these is: (3) The use of soluble persulphates, of which iron is the only practical example, as a solvent. The Siemens & Halske process is the classic example of this:

$$Cu_2S + 2Fe_2(SO_4)_3 = 2CuSO_4 + 4FeSO_4 + S$$
$$CuO + Fe(SO_4)_3 = CuSO_4 + Fe_2(SO_4)_2O$$

(4) Closely allied to (2) is the process used at Stadtberge and Linz, Germany, in which oxidized ores were treated with sulphur dioxide and nitrous gases. Intermediate between two main groups of sulphate and chloride leaching stands: (5) the Dötsch process, used at Rio Tinto, Spain. In this process, ferric sulphate and salt are the reagents, the equations being essentially:

$$CuS + Fe_2Cl_6 = 2FeCl_2 + CuCl_2 + S$$
$$Cu_2S + Fe_2Cl_6 = 2FeCl_2 + Cu_2Cl_2 + S$$

The liquor is regenerated, after precipitation of the copper, by running it down through chlorine towers, the gas being produced by heating salt and ferrous sulphate in an oxidizing atmosphere in reverberatories:

$$2FeSO_4 + 4NaCl + 3O = Fe_2O_3 + 2Na_2SO_4 + 4Cl$$

The Hunt-Douglas process also falls into the same class. Among the chloride-leaching processes the use of (6) hydrochloric acid has been proposed but does not seem to be in commercial use anywhere at present. (7) Höpfner uses cupric chloride:

$$CuCl_2 + CuS = Cu_2Cl_2 + S$$

while the use of ferrous chloride is theoretically attractive:

$$3CuO + 2FeCl_2 = Fe_2O_3 + CuCl_2 + Cu_2Cl_2$$
$$3CuCO_3 + 2FeCl_2 = Fe_2O_3 + Cu_2Cl_2 + CuCl_2 + 3CO_2$$

Practically, however, the reactions are slow, precipitation of the copper expensive, and regeneration of the "ic" salts incomplete. (8) The Longmaid-Henderson process first calcined the ores, then roasted with *abraumsalz*, a mixture of sodium, po-

tassium, magnesium and calcium chlorides. In an absolutely different class of reagents come: (9) Ammonium carbonate or (10) ammonia. The great difficulty with these processes has been the loss of the reagents by volatilization, but the ammonia-leaching process is now to be given a thorough trial at Lake Linden, Mich., under the auspices of the Calumet & Hecla Company. (11) Last is the theoretically beautiful leaching with sodium thiosulphate, which appears to be a practical failure through the ready decomposition of the reagent and the inhibitory effects of calcium compounds. (12) Leaching with nitric acid is to be tried by the Nevada-Douglas Copper Co. at Ludwig, Nev.

Any review of leaching would be incomplete without some reference to the ingeniously worked out Bradley process.[1] The ore was carefully roasted to a sulphate and most of the iron was converted into insoluble ferric oxide. This must be done at temperatures between 450°C. and 550°C. The roasted ore was then brought into association with an excess of calcium-chloride solution in a reaction drum at about a temperature of 100°C. Cupric chloride was produced by the reaction between the copper sulphate and the calcium chloride, while any ferric sulphate in the roasted product reacts with the calcium chloride to produce ferric chloride. The calcium sulphate from both these reactions is of course insoluble and is separated by filtration in the succeeding step.

From this solution the iron and alumina was precipitated by cupric oxide, hydrate, or calcium carbonate, which carries down some copper. This precipitate was therefore returned to the sulphatizing-roasting process, in which the bulk of the iron and alumina were rendered insoluble, while the copper was converted into soluble copper sulphate.

The solution from which the iron and alumina had been removed and which contained the bulk of the copper was run into a second tank in which copper was precipitated by calcium carbonate as oxide of copper. The precipitate was filtered off and the copper recovered, while the calcium chloride was regenerated for use on further quantities of ore. There were also modifications for recovery of the silver, gold and zinc in the ore. Apparently its own chemical complications caused its failure.

In the consideration of any leaching process the first factor is the character of the ore. Thus, an ore containing large amounts of calcium carbonate obviously cannot be successfully leached with any free-acid reagents. The same would equally apply to ores containing large amounts of soluble alkalies, magnesia, alumina, etc. The leaching agent will be determined partly by the character of the ore and partly by its own cost. The reagent most generally available and cheapest is sulphuric acid. Ample wash water is a *sine qua non*, while the last great question is that of a precipitating agent. On this we are at once reduced to iron, sulphur dioxide under pressure, electrolysis and calcium carbonate or hydrate.

[1] U. S. Pat. No. 1,011,502.

Scrap iron, after the floating supply of tin cans has been utilized is likely to be an expensive commodity. Using a fairly pure copper sulphate solution, the consumption of iron is likely to run from 1¼ to 1½ lb. of iron per pound of copper produced. Where the solutions are high in chlorides, as in the Dötsch process at Rio Tinto, the consumption of iron is said to run as high as 2½ lb. of iron per pound of copper produced. However, I do not feel that the possibilities of sponge iron, *i.e.*, iron produced by the reduction without fusion of ferric oxide, have by any means been exhausted, and that the great hope of chemical precipitation lies in this material.

Electrolysis looks fine on paper, like everything else connected with leaching. However, as ordinarily conducted there will be constant trouble with the anodes, and only about 1 lb. of copper will be deposited per kilowatt-hour. According to theory, if sulphur dioxide can be introduced under proper conditions, the anode can be depolarized and the electrolytic cell made to be practically a primary battery. Working along these lines Lawrence Addicks claims to have obtained a deposit of 2½ lb. of copper per kilowatt-hour.[1] But it is by no means certain that high enough current densities can be used when this efficiency is being obtained to make the process a commercial one.

However, the factors of solution and precipitation will ordinarily be settled by purely commercial considerations, *i.e.*, some one solvent and some one precipitant will probably be the one that must be made to work if the process is to be successful. The question of water supply must be settled by the proper locating of the works.

Other details on which experimental work will have more of a chance to pick and choose are such matters as fineness of crushing, upward or downward percolation, percolation vs. agitation, strength of lixiviant, the control of impurities in the solution, both as to their control when there, and preventing them going into solution, the slime problem, adsorption of copper by the ore and the proper amount of wash water. This will probably seem a very summary dismissal of the leaching problem. So it is. The process has not arrived at the stage of having constants or published working costs and conditions.

Precipitation of Silver from Cyanide Solution

Precipitation from cyanide solution is by deposition of the dissolved metal upon zinc, either in the form of shavings or dust, or upon aluminum in the form of dust, or by electrolysis. Zinc dust is at present the most usual precipitant, although aluminum has some advantages, in that it does not form any cyanogen compound. Electrolysis has been a popular process, but at the present time it is considered too expensive for general use. One ounce of silver requires about one ounce of zinc or one-third of an ounce of aluminum for its precipitation.

[1] *Eng. and Min. Journ.*, Jan. 9, 1915.

Sulphur-sand Cement[1]

Sulphur-sand cement is composed of 1 part sulphur and 1.4 parts quartz sand ground to pass at least a 60-mesh screen. The mixture is heated to about 150°C. when it flows nicely and is sufficiently above the melting point of sulphur, 114°C., to prevent sudden chilling. The fact that sulphur begins to thicken above 156°C. and becomes so viscid that it will not flow at 180°C. must be borne in mind or there will be difficulty in working the cement. This is possibly the most satsifactory general cement available for low temperature work. It is readily handled and remarkably strong, has a tenacious bond is free from cracking and inert to most solutions. It will be found valuable for large-scale work, as well as in the laboratory. It was developed by CHARLES S. BRADLEY for use in his copper-leaching process.

SIZES AND CAPACITIES OF BULLION MOULDS[2]

Inside measure			Capacity, gold, Troy oz.	Silver, Troy oz.	Weight of mould, lb.
Length, inches	Width, inches	Depth, inches			
1	5/8	1/2	4	2	1
1 1/2	1	3/4	10	5	1
2 1/4	1 1/16	1	25	12	1
3 3/8	1 3/8	1 1/8	50	25	3
3 1/2	2	2	95	50	6
4	2	1 3/4	100	56	7
4 1/4	2 1/4	2	136	76	9
4 1/2	2 1/2	2 1/4	180	100	10
5	2 1/2	2 1/4	244	134	10
5 1/8	2 3/4	2 1/4	250	140	10
5 1/2	2 5/8	2 3/4	295	166	11
5 1/2	3	2 3/4	365	200	12
5 3/4	3	2 3/4	375	208	13
6 1/2	3 1/4	3 1/4	550	300	15
6 3/4	3 1/2	3 1/4	620	340	19
7 1/2	3 1/2	3 1/4	730	400	28
8	3 3/4	3 1/2	910	500	35
9	3 3/4	3 1/2	1015	600	36
9 1/2	4	3 1/2	1285	700	40
9 1/2	4 1/2	3 1/2	1448	800	41
10	4	4	1470	810	42
10 1/2	4	4	1650	900	55
11	4 1/2	4	1830	1000	65
11	4 1/2	4 1/2	2200	1200	72
11 1/2	5	5	2750	1500	76

[1] E. J. HALL, *Eng. and Min. Journ.*, July 17, 1915.
[2] As made by FRASER & CHALMERS.

Briquetting

For the purpose of agglomerating flue dusts and fine ores there are a number of binders and methods. Among the binders may be mentioned cement, concentrator slime, milk of lime, molasses refuse (which usually leads to a convention of flies assembling from all the neighboring states), ferric- or ferrous-sulphate solutions, magnesium- or calcium-chloride solution (the use of 5 to 10 per cent. of magnesium- or calcium-chloride solution, equivalent to 0.25 to 2 per cent. of $MgCl_2$ or $CaCl_2$, followed by compression, constitutes the patented SCHUMACHER process), and various asphaltic and tarry residues.

Of the various methods used with these binders may be mentioned hand-moulding, brick-press moulding (square form), round briquettes (CHISHOLM-BOYD-WHITE machine), briquettes cut from continuous stream (CHAMBER'S brick machine), the use of bags, and agglomeration in HUNTINGTON-HEBERLEIN pots or DWIGHT-LLOYD roasters for lead ores, and on DWIGHT-LLOYD machines or in cement kilns for flotation concentrates.

For metallic chips the RONAY process is probably best.

This method is one for briquetting metallic chips without a binder. The divided metal particles are subjected in a mould to pressures of about 30,000 lb. per square inch. The briquette is allowed to remain under pressure a sufficient time to expel all the air and moisture, having been previously freed from dust and dirt.

A general résumé of the subject of briquetting for iron-blast furnace work is abstracted by the *Journal of the Society of Chemical Industry*, Oct. 30, 1915, from Le Génie Civil, 1913, p. 306, and *Revue de Metallurgie*, 1915, p. 138. To be serviceable in a blast furnace, briquettes should satisfy the following tests: (1) fall from a height of 3 to 4 m. on to a metal plate without being reduced to powder, and withstand a pressure of about 140 kg. per square centimeter; (2) withstand a temperature of 900°C. without being reduced to powder; (3) stand in water for some time without softening; (4) withstand steam at 150°C. without being reduced to powder; (5) be sufficiently porous to absorb 12.5 to 16 per cent. by volume of water on being immersed for 25 minutes. The briquettes should be free from sulphur, arsenic, and other objectionable materials, and the cost of briquetting must not be greater than the difference in value of the ore in lump and as smalls.

Methods of Briquetting.—(1) (YEADON). 5 to 10 per cent. of slaked lime is added and the mixture made into a paste with water. Briquettes are formed under a pressure of 400 kilos per square centimeter and are placed in the open air to dry and harden. This requires at least 2 months. To avoid this delay steam under pressure is sometimes used, or about 10 per cent. of sawdust is added to the mixture and the briquettes are heated to 1200°–1400°C., when the wood carbonizes and the particles of ore frit together. (2) A mixture of equal parts of lime and sand is used as the agglomerant. (3) (SCHUMACHER). Fresh blast-furnace dust is briquetted with magnesium chloride

as binder. (4) Basic blast-furnace slag is used as the agglomerant for dust, hardening being effected by high-pressure steam. If the dust is deficient in lime, 4–4.5 per cent. of this material is added. (5) An intimate mixture of ore, limestone, and moistened cement is briquetted under a pressure of 400 kilos per square centimeter. The briquettes are serviceable after standing in the open air for 3 or 4 days. (6) (Weiss). Briquettes containing 5–6 per cent. of slaked lime are compressed at 300 kilos per square centimeter and subjected to the action of carbon dioxide under a pressure of 20 kilos per square centimeter, first in the cold and then hot. The treatment requires about 5 hours, after which the briquettes are serviceable. (7) (Ronay). Blast-furnace dust or roasted pyrites is compressed hydraulically into briquettes, without the addition of binders, under a pressure of about 1000 kilos per square centimeter. (8) (Gröndal). Impure ores are ground and concentrated in magnetic separators. The ore-mud is formed under small compression into briquettes, which are then passed on wagons of special construction through gas-fired tunnel furnaces. The highest temperature reached is 1300°–1400°C., which causes the particles to frit together and drives off sulphur. The briquettes are of high quality.

Recent German Blast-furnace Practice.—A writer in *Stahl und Eisen* gives the following comparison of the space used per ton of pig iron in Germany 30 years ago with present practice. Our translation is taken from *The Iron Age*. The particulars are the average of forty-three furnaces:

Iron	30 years ago	Present practice	
		Daily output	Per ton
	Cubic meters	Tons	Cubic meters
Foundry iron	5.5–5.0	185	2.89
Spiegeleisen	4.5–5.5	165	2.22
Open-hearth steel-making iron	3.5–4.5	350	1.34
Basic-Bessemer iron	2.5–3.3	450	1.28
		280	1.10

In a similar way the time required for the charge to work through the furnace has decreased considerably during the last 10 years. For basic-Bessemer iron it varies from 10 to 25 hours, the lower time for Westphalia and the higher for the Minette district. For open-hearth steel-making iron it is from 14 to 21 hours, for hematite 15 to 30 hours, and for foundry iron 16 to 27 hours. For spiegeleisen the time varies from 24 to 27 hours. For 80 per cent. ferro-manganese the time required is 20 hours with about 205 per cent. coke consumption, 18 hours with 230 per cent., and 12 hours with 260 per cent.; all for 90 tons daily output. For 12 per cent. ferro-silicon, with about 125 tons

daily output, it is about 14 hours with 215 per cent. coke consumption, and 12 hours with 225 per cent. The advantage of a wide throat that favors a uniform descent of the charge has found greater and greater recognition, so that diameters of over 5200 mm. (17 ft.) are not uncommon today, with a ratio to the diameter at the bosh line of 0.8, which makes the angle of the stack very steep. This angle is usually about 86 deg.; in particular, for furnaces making foundry iron it is 85 to 87 deg., for those making open-hearth steel-making iron, 81½ to 86½ deg., and for those making basic-Bessemer iron, 81 to 86½ deg. With large outputs the bosh angle is 76 deg., although there are some exceptions. In particular, for furnaces making foundry iron the lowest case is 67 deg., the highest 77 deg.; for furnaces giving open-hearth steel-making iron the angle is 70½ to 77 deg., and for those making basic-Bessemer iron, 71½ to 76½ deg. If the cross-section of the tuyères per ton of coke is compared for modern blast furnaces, considerable differences are found, and this is also true of the blast pressure. No settled ratio between these quantities can be noticed. For instance, the results of the forty-three furnaces give the following:

Iron	Tuyère section per ton coke	Pressure
Foundry iron	3.84–13.3 sq. cm.	14.0–24 cm.
Open-hearth steel-making iron	5.8 –12.6 sq. cm.	22.5–75 cm.
Basic-Bessemer iron	3.6 – 9.32 sq. cm.	24.0–68 cm.

Some Constants for the Metallurgy of Iron

Heat Content of Pure Iron[1]

Temp.	Total heat	Temp.	Total heat	Temp.	Total heat
250	30.5	750	125.6	1250	208.3
300	37.7	800	135.8	1300	216.1
350	45.0	850	144.4	1350	224.2
400	52.2	900	152.8	1400	233.1
450	60.3	950	160.4	1450	241.4
500	68.3	1000	167.8	1500	250.0
550	76.7	1050	175.4	....	....
600	85.0	1100	183.0	....	....
650	95.1	1150	191.7	....	....
700	111.8	1200	200.0	....	....

Shrinkage of Castings per Foot

Cast iron	⅛ in.	Zinc	5/16 in.
Brass	3/16 in.	Tin	1/12 in.
Steel	¼ in.	Aluminum	3/16 in.
Malleable iron	⅛ in.	Britannia	1/32 in.

[1] P. Overhoffer, *Metallurgie*, June 22, July 8 and 22, 1907.

Pig-iron Converting Data

	C, per cent.	P, per cent	Si, per cent.	Mn, per cent	S, per cent.
Charge	2.98	0.10	0.94	0.43	0.06
After blowing 9 min. 10 sec.	0.04	0.11	0.02	0.01	0.06

Slag formed: SiO_2, 63.56 per cent.; Al_2O_3, 3.01; FeO, 21.39; Fe_2O_3, 2.63; MnO, 8.88; CaO, 0.90; MgO, 0.36.

Gases produced: CO_2, 5.20 per cent., CO, 19.91; H_2, 1.39; N_2, 73.50 per cent.

Heat Balance Sheet (Blowing 22,500 Lb. of Above Pig)

Heat in converter body at starting	8,034,970
Heat in melted pig iron	6,750,500
Heat in spiegeleisen	750,000
Heat in blast	86,580
Heat of oxidation	4,510,800[1]
Heat of formation of slag	59,890
Total on hand and developed	20,192,740
Heat in converter body at finish	7,183,770
Heat in finished steel	8,632,750
Heat in slag	1,582,350
Heat in escaping gases	2,786,000
Heat absorbed in decomposing moisture	182,130
Heat conducted to the air	34,630
Heat lost by radiation	25,240
Total accounted for	20,426,870

[1] Derived as follows:

C to CO_2	1,139,670 cal.
C to CO	1,309,280 cal.
Si to SiO_2	1,422,400 cal.
Mn to MnO	327,130 cal.
Fe to FeO	268,150 cal.
Fe to Fe_2O_3	44,170 cal.
	4,510,800 cal.

Tempering Ordinary Steel

Deg.	Color
200	Yellow
250	Brown
300	Light blue
350	Dark blue

STEEL CONVERTING—HEAT EFFECT OF OXIDIZING 1 KG. OF MATERIAL

	Heat of oxidation	Formation of slag	Total heat developed	Chilling effect of blast, radiation, etc.	Net heat available for raising temperature	Theoretical rise in temperature
						Deg.C.
Silicon	7,000	......	7,000	1,688	5,312	188
Manganese	1,653	98	1,751	430	1,321	51
Iron (to FeO)	1,173	159	1,332	422	910	33
Iron (to Fe_2O_3)	1,746	159	1,905	825	1,080	42
Titanium	4,542	......	4,542	1,022	3,520	133
Aluminum	7,272	......	7,272	1,305	5,967	224
Nickel	1,051	159	1,210	378	832	33
Chromium	2,344	......	2,344	887	1,457	56
Carbon (to CO_2)	8,100	......	8,100	3,936	4,164	143
Carbon (to CO)	2,430	......	2,430	2,572	−142	−5
Phosphorus	5,897	2,572	8,469	{2,477 / 2,253[1]}	3,739	133

Basic-lined Open Hearth (Monell Process)[2]

Fifty tons pig iron at 1300°C. run in on 15 tons of ore (90 per cent. Fe_2O_3; 10 per cent. SiO_2) also heated to 1300°C. There is 2000 lb. CaO on the ore. The reaction requires about 20 minutes.

ANALYSIS OF METAL

	On running in	After reaction
Carbon	3.50	3.00
Silicon	2.00	0.00
Phosphorus	0.75	0.00
Manganese	0.50	0.00
Iron	93.25	97.00

	Heat evolved	Cal.
Si to SiO_2	$2{,}000 \times 7{,}000 =$	14,000,000
P to P_2O_5	$750 \times 5{,}892 =$	4,419,000
Mn to MnO	$500 \times 1{,}653 =$	826,500
C to CO	$471 \times 2{,}430 =$	1,144,500
SiO_2 to $FeO \cdot SiO_2$	$7{,}286 \times 144 =$	1,049,200
CaO to $3CaO \cdot P_2O_5$	$2{,}000 \times 949 =$	1,898,000
		23,337,200

[1] Chilling effect of lime added, preheated to 600°.
[2] J. W. RICHARDS, "Metallurgical Calculations," Vol. II.

	Heat absorbed	Cal.
O_3 to FeO	18,900× 573 =	10,829,700
) to Fe	4,681×1,173 =	5,490,800
C to Fe_3+C	471× 705 =	332,000 (?)
Si to Fe+Si	2,000× 931 =	1,862,000 (?)
P to Fe_3+P	750×1,400 =	1,050,000 (?)
		19,564,500 (?)

BALANCE SHEET OF IRON BLAST FURNACE[1]
(Per 1000 Units of Pig Iron)

Charges		Pig iron		Slag		Gases	
	1530.2						
Fe_2O_3	1314.9	Fe	920.4			O	394.5
FeO	60.6	Fe	46.2	FeO	1.2	O	13.2
SiO_2	84.2	Si	6.0	SiO_2	69.6	O	8.6
MnO	9.6	Mn	0.25	MnO	9.3	O	0.1
Al_2O_3	11.6			Al_2O_3	11.6		
CaO	34.1			CaO	34.1	O	0.03
MgO	14.8			MgO	14.8		
P_2O_5	0.092	P	0.04			O	0.05
S	0.153	S	0.07	CaS	0.19		
Cu	0.11	Cu	0.11			O	0.01
estone	115.8						
Fe_2O_3	0.2			FeO	0.2	O	0.02
SiO_2	3.6			SiO_2	3.6		
Al_2O_3	0.4			Al_2O_3	0.4		
CaO	62.2			CaO	62.2		
MgO	0.2			MgO	0.2		
P_2O_5	0.007	P	0.003			O	0.004
S	0.001			CaS	0.0		
CO_2	49.1					CO_2	49.1
rcoal	682.0						
C	547.7	C	27.0			C	520.7
N	0.5					N	0.5
O	24.1					O	24.1
Fe_2O_3	2.2			FeO	2.0	O	0.2
SiO_2	1.3			SiO_2	1.3		
CaO	6.1			CaO	5.9	O	0.06
MgO	0.7			MgO	0.7		
P_2O_5	0.046		0.02			O	0.03
S	0.116			CaS	0.25		
K_2O	3.4			K_2O	3.4		
H_2O	95.8					H_2O	95.8
st	2416.8						
O_2	557.7					O	557.7
N_2	1859.1					N	1859.1
otals	4744.8		1000.0		220.8		3543.7

[1] J. W. RICHARDS, "Metallurgical Calculations," Vol. II.

Heat Balance, Iron Blast Furnace[1]

(Per 100 Kg. of Iron)

Heat developed	Dry blast
C to CO	92,950 Cal.
C to CO_2	206,955 Cal.
Heat in blast	37,850 Cal.
Solution of carbon in iron	2,820 Cal.
Formation of slag	4,260 Cal.
	344,835 Cal.

Heat accounted for	Dry blast
Reduction of iron	165,870
Reduction of silicon	7,000
Expulsion of CO_2	18,666
Evaporation of moisture	11,342
Heat in waste gases	23,799
Decomp. of blast moisture	3,225
Heat in slag	29,280
Heat in pig iron	32,500
Heat in cooling water	14,922
Lost by radiation and conduction	37,791
	344,835
Carbon burnt at tuyères	58.05
Total fixed carbon charged	67.8
Proportion burnt of tuyères	85.6
Fixed carbon really available	62.9
Proportion burnt at tuyères	92.3

Cupola Charges in Stove Foundries[2]

	Foundry *A*	Foundry *B*	Foundry *C*	Found *D*[3]
Bed of coke	1500	1600	1600	1800
First iron charge	5000	1800	4000	5600
All other iron charges	1000	1000	2000	2900
First charge of coke	200	150	200	200
Second charge of coke	200	130	200	200
Four next charges	150	130	150	200
Six next charges	120	100	150	200
All other charges	100	100	150	200

[1] J. W. Richards, "Metallurgical Calculations," Vol. II.
[2] Kent's, "Mechanical Engineers' Pocket Book."
[3] A very high melting ratio for stove plate. About 8 to 14 necessary for good melting. The metal loss will probably run per cent.

WASHING GASES WITH THIESSEN WASHER

	Hochdahl		Schalke	Hörde		Rombach
	Apparatus I, hot uncleaned gas	Apparatus II		Apparatus I, cool cleaned gas	Apparatus II	
grains per 1000 ı. ft.:						
ɔre washing.....	2.6	2.6	1.3–1.7	1.1	1.0	0.87
·r washing......	0.017	0.008	0.008	....	0.004	0.008
, grains per 1000 ı. ft.:						
ɔre washing.....	7.8	10.4	15.0 % vol.	13.9	15.8	18.3
·r washing......	3.1	2.2	12.20 % vol.	1.5	1.3	13.9
ɜrature of gas, ɜg. C.:						
ɔre washing.....	144.0	158.0	144.0	46.0	45.0	43.0
·r washing......	30.0	37.0	30.0	33.0	28.0	36.0
ɜrature of water, ɜg. C.:						
ɔre washing.....	14.0	7.0	12.0	28.0	20.0	18.0
·r washing......	39.0	40.0	55.0	37.0	34.0	19.0
g water consumed:						
ic feet per hour..	667.0	424.0	360.0	565.0	247.0	360.0
per 1000 cu. ft..	8.22	7.48	7.48	7.78	7.93	8.45
e of gas per hour, c feet..........	607,160	423,600	360,060	529,500	211,800	317,700

ɔFMAN'S "General Metallurgy."

STEEL ROLLING

C MILLIMETERS OF STEEL DISPLACED BY 1 KG.-M. OF ENERGY AT DIFFERENT TEMPERATURES[1]

ɜre ingots to	At temperatures, deg. C.			
	1300	1200	1000	900
....	100	45	20	18
ds.........	80	50	....	....
ɜers........	85	67	20	10
....	....	70	20	....

FMAN'S "General Metallurgy," p. 665.

Types of Electric Furnaces

Electric furnaces may be divided into three classes: (1) Arc; (2) resistance; (3) induction furnaces, according to the different methods of applying the heat.

In the arc furnaces the heating is produced by radiation or conduction from an electric arc. This arc is formed by the passage of an electric current at 50 to 120 volts across the air gap between two carbon electrodes, or between one or more carbon electrodes and the surface of the molten metal, which then acts as the second pole of an electric circuit.

In resistance furnaces the heat effect is produced within the metal itself by the resistance offered to the passage of the current through it. The temperature attained by this method of heating cannot equal that attained in arc heating; the radiation and conduction losses are lower and the thermal efficiency of the furnace is higher.

Induction furnaces form really a subdivision of the resistance type of furnace, since the thermal effect is again due to the resistance of the metal to the flow of current through it. In this case, however, induced currents of electricity are used in place of direct current. The induction furnace is in fact nothing but a great step-down transformer in which a ring of molten metal forms the secondary circuit and becomes the focus of current of large intensity but low e.m.f. The disadvantages of this type of furnace are its comparatively low temperature and the necessity for retaining a certain proportion at every melt in the annular ring in order to carry the current for melting the next charge. A great advantage is that electrodes are dispensed with and that this costly item of running charges is wiped out. A secondary advantage is that the capital expenditure upon cables and conductors is greatly reduced.

The chief commercial types of furnace fall into the classes as follows: (1) arc—CHAPLET, GRÖNWALL, GIROD, HEROULT, KELLER, NATHUSIUS, SNYDER, STASSANO; arc and resistance—HÄRDEN, NAU, SODERBERG, STOBIE; resistance—ROCHLING, RODENHAUSER, QUENEAU (pinch effect), HERING (pinch effect); induction—ANDERSON, COLBY, FRICK, HIORTH, KJELLIN.

Composition of the Silicides and Carbides[2]

Ni_2Si, Co_2Si, Cr_2Si, Mn_2Si, Cu_2Si, Fe_2Si,[3] $FeSi$,[3] W_2Si_3.

1	2(*a*)	3(*b*)	4(*c*)	5(*f*)	6(*d*)	7(*f*)	8(*f*)	9(*e*)	10(*f*)
Li_2C_2..	CaC_2 SrC_2 BaC_2	CeC_2 LaC_2 YtC_2 ThC_2	U_2C_3	WC	Al_4C_3 Be_4C_3	Cr_3C_2	MoC W_2C	Mn_3C Fe_3C	Cr_4C ......

(*a*) All carbides of this group give acetylene when decomposed with water. (*b*) These carbides give off complex mixtures of acetylene, ethylene, methane and hydrogen, according to temperature employed. (*c*) This carbide when decomposed with water gives gases rich in methane. Only about one-third of the carbon is given off in this way, the remainder forms liquid and solid hydrocarbons and carbohydrates. (*d*) These carbides and water ·methane only. (*e*) Manganese carbide and water give equal mixtures ·hane and hydrogen. Iron carbide is not decomposed. (*f*) These ·s are not decomposed by water.

[2] ·rding to BORCHERS' "Electric Smelting and Refining."

[3] ·e silicides alloy with silica in all proportions.

Electric Steel Furnaces[1]

POWER CONSUMPTION IN KILOWATT-HOURS PER METRIC TON OF STEEL PRODUCED

	Cold charges composed of			Molten charges from				
	Scrap	Pig iron and Walloon iron	Average	Bessemer	Wellman open hearth	Martin open hearth	Cupola	Average for molten charges
Heroult	459			104				
	528		493	33	200			146
Girod	750				200			
	850		800		275			237
Stassano	918							
	958							
	1000							
	1250							
	1260		1071					
Röchling-	640			125				
Rodenhauser				150	280		280	
	780			200				
	900		773	250				214
Frick	780							
	800		790					
Keller						275		275
Hiorth		680						
		720						
		790	730					
Colby	605							
	825		715					
Kjellin	650							
	790							
	800		747					

Power Consumption in Ferro-chrome Making[2]

The power consumption in a ferro-chrome furnace of the Meraker Electric Smelting Co., at Kopperaaen, Norway, was recently given as 3 kw.-hours per pound, or 0.68 kw.-year per short ton in making a ferro-chrome containing 5 per cent. carbon. At Kanawha Falls, W. Va., ferro-chrome was made in a crucible electric-arc furnace with a power expenditure of 3.6 kw.-hours per pound, or 0.72 kw.-year per ton. This product contained 70.96 per cent. chromium, 23.23 per cent. iron, 5.21 per cent. carbon, 0.5 per cent. silicon, 0.008 per cent. phosphorus, and 0.078 per cent. sulphur. At both Kopperaaen and Kanawha Falls an ore containing about 50 per cent. Cr_2O_3 was

[1] JOHN B. KERSHAW, "Electrothermal Methods of Iron and Steel Production."
[2] *Iron Trade Review*, May 13, 1915.

used. The Kopperaaen ferro-chrome contains 65 to 70 per cent. chromium. In the experiments of the writer, a product containing 50 to 68 per cent. chromium and 4.32 to 9.31 per cent. carbon was obtained with an ore containing 46.35 per cent. Cr_2O_3, and power consumption of 3.02 kw.-hours per pound or 0.69 kw.-year per ton. A 750-kw. furnace of the Alby Carbide type at Kopperaaen, operating continuously, used on the average about 3 kw.-hours per pound of ferro-chrome produced, or 0.68 kw.-year per short ton, when chromite ore containing 50 per cent. Cr_2O_3 is charged; and the product contains 5 per cent. or more of carbon and 65 per cent. of chromium.

SECTION XI

FIRST AID

TRUCTIONS FOR FIRST-AID TREATMENT[1]

ıds that Bleed—Abrasions, Cuts, Punctures.—Drop 3 t. alcoholic iodine into wound freely; then apply dry ;auze to wound and bandage it. Do not otherwise wound.

e Bleeding.—Place patient at rest and elevate injured Apply sterile gauze pad large enough to allow pressure ɔove and below wound. Bandage tightly.

ere bleeding continues apply tourniquet between wound rt and secure doctor's services at once. Use tourniquet ıtion and only after other means have failed to stop .

Bleeding.—Maintain patient in upright position with ›vated. Have him breathe gently through mouth and / nose. If bleeding continues freely, press finger firmly ›nt's upper lip close to nose or have him snuff diluted ine vinegar into nose.

es which do not Bleed—Bruises and Sprains.— ıjury with several layers of sterile gauze or cotton, ndage tightly. Application of heat or cold may help, eans are unnecessary. If injury is severe place patient and elevate injured part until doctor's services are

njuries—Except Eye Burns.—For ordinary eye irrita- od eye with 4 per cent. boric acid solution. Remove ɔse particles which can be brushed off gently with ıt cotton wrapped around end of toothpick or match. ıt remove foreign bodies stuck in the eye. In that case other eye injuries, drop castor oil freely into eye, apply ıuze, bandage loosely and go to doctor.

Electrical and Sun Burns.—Do not open blisters. Use ıtment (3 per cent. bicarbonate of soda in petrolatum) ı sterile gauze applied directly to burn. Cover with hicknesses of flannel or soft material, then bandage but tly.

3urns.—Thoroughly flush wound with water, then dry apply burn ointment and bandage as above.

[1] a Bulletin of the Conference Board on Safety and Sanitation Affiliated Safety Organizations; M. W. ALEXANDER, Secretary, n, Mass.). Copyright, 1914. Reprinted from *Engineering News*.

Alkali Burns.—Thoroughly flush wound with water, t flood with white wine vinegar to neutralize (dilute vinegar alkaline eye burns), dry wound, apply burn ointment bandage as above.

Asphyxiation or Electric Shock.—See page 587.

Burns and Scalds.—Cover with cooking soda and lay cloths over it. Whites of eggs and olive oil. Olive or lin oil, plain, or mixed with chalk and whiting.

Chills and Cramps.—Give patient 20 to 30 drops of Jam ginger in hot or cold water. If no improvement, send for do

Cinders in the Eye.—Roll soft paper up like a lamp lighter wet the tip to remove, or use a medicine dropper to draw it Beware of infecting the eye with a dirty handkerchief corn similar material. Rub the other eye.

Dislocations.—In case of dislocation of finger except sec joint of thumb, grasp finger firmly and pull it gently to rep joint, then place finger in splint and bandage. In other c rest dislocated part and secure doctor.

Fainting.—Place flat on back; allow fresh air, and spri with water.

Fractures.—Make patient comfortable and secure doct services at once. Avoid unnecessary handling to prevent sl edges of broken bones tearing artery. If patient must moved, place broken limb in as comfortable position as pos and secure it by splint.

Frost Bites.—Rub with ice, snow or cold water; then t as "fire burns."

Heat Prostration.—Give patient teaspoonful of aromatic s of ammonia in hot or cold water. In case body feels warm a cold to it; if necessary give cold bath. In case body feels and clammy, apply heat to it and send for doctor.

Internal Poisoning.—Immediately secure doctor's servi Make patient drink large quantities of water, preferably wa and make him vomit by sticking one's finger down his throa by other means.

Lightning.—Dash cold water over a person struck.

Mad Dog or Snake Bite.—Tie cord tight above wound. S the blood and cauterize with caustic or white hot iron at on or cut adjoining parts with a sharp knife.

Shock, Following Injury.—In case shock is due to severe ble ing, control it first as directed under "severe bleeding" summon a doctor.

Lay patient flat on back and keep him warm with blank hot-water bottles, etc., and provide plenty of fresh air. patient inhale fumes of aromatic spirit of ammonia. If fi conscious give patient hot drink or teaspoonful of arom ammonia in hot or cold water.

Sunstroke.—Loosen clothing. Get patient into shade, a apply ice-cold water to head.

Venomous Insect Stings, Etc.—Apply weak ammonia, oil, s water, or iodine.

ANTIDOTES FOR POISONS

ɜt.—Send for a physician.
:ond.—Induce vomiting by tickling throat with feather or , drinking hot water or strong mustard and water.
ɔw sweet oil or whites of eggs.
ds are antidotes for alkalies, and *vice versa.*

Special Poisons and Antidotes

.—Muriatic, oxalic, tic, sulphuric (oil of :iol), nitric (aqua tis).	Soap-suds, magnesia, lime-water.
꞉ic **Acid.**	Ammonia in water. Dash water in face.
ɔlic **Acid.**	Flour and water, mucilaginous drinks.
ies.—Potash, lye, ·tshorn, ammonia.	Vinegar or lemon juice in water.
ɪic.—Rat poison, :is green.	Milk, raw eggs, sweet oil, lime-water, flour and water.
Poison.—Lead, salt-re, corrosive subli-te, sugar of lead, e vitriol.	Whites of eggs, or milk in large doses.
·oform.—Chloral er.	Dash cold water on head and chest. Artificial respiration.
ɔnate of **Soda.**—pperas, cobalt.	Soap-suds and mucilaginous drinks.
e.—Antimony, tar-emetic.	Starch and water, astringent infusions. Strong tea.
:ury and its salts.	Whites of eggs, milk, mucilages.
m.—Morphine, danum, paregoric, ɔthing powders or ·ups.	Strong coffee, hot bath. Keep awake and moving at any cost.

CYANIDE POISONING

is recommended that boxes labeled "Antidotes for ıide," with directions for use affixed to the lids of the boxes, d be kept in prominent and easily accessible parts of the ide plants. Each box should contain: a spoon and a l receptacle to hold about 1 pt.; one blue hermetically d vial containing 30 cc. of 33 per cent. solution of ferrous ıate; a white vial containing 30 cc. of 5 per cent. caustic-ɜh solution; and one package, 30 grains, of oxide of magne- (light). The directions for the use of the antidote should ; follows:

eparation of Antidote.—Quickly empty the contents of the vial, of the white vial, and of the magnesia package into ıetal receptacle, and stir well with the spoon. This should

be done as rapidly as possible, as the patient's chance of l
depends on promptness.

Administration of the Antidote.—If the patient is conscio
make him swallow the mixture at once and lie down for a f
minutes. If the patient is not conscious, place him on his b
and pour the mixture down his throat in small quantities,
necessary pinching his nose in order to make him swallow.

Incite Vomiting.—After the antidote has been given, try
make the patient vomit by tickling the back of the throat wit
feather or with the fingers, or giving a tumblerful of warm wa
and mustard.

Then call the undertaker.

For cyanide eczema use equal parts by weight of calomel a
bismuth subnitrate and apply locally. It will give immedi
relief and will dry up the sores in 2 or 3 days.

Other prescriptions are as follows:

Add 3 oz. of camphor to 1 pt. of olive oil and dissolve
slow heat. This occasions some pain when first applied l
will soon afford relief.

In mild cases the following will be beneficial: zinc oxide ½ c
zinc carbonate 30 grains, glycerin ½ oz., lime water to ma
½ pt.

For sores which do not heal use: pure lard 5 oz., olive
5 oz., white wax 2½ oz., spermaceti 2½ oz., powdered g
benzoin 12 oz.

For selenium poisoning under the fingernails, brush the en
of the fingers with 5 per cent. cocaine solution.

FIRST AID FOR GAS ASPHYXIATION OR ELECTR SHOCK

In line with its campaign to reduce the number of deat
in the mines of the United States, the Federal Bureau of Mi
some time ago appointed a committee of eminent physicia
and surgeons to develop an efficient method of resuscitation
be administered by miners or other persons to a fellow-workm
overcome by electric shock or by gases in places which cannot
reached by a physician or surgeon in time to save life.

As a result of this committee's report the Bureau recommen
the following procedure in rendering first aid to those in need
artificial respiration.

The recommendations apply not only to men who are ove
come by electric shock or gases in mines, but also to persons su
fering from the effects of illuminating-gas poisoning or fro
electric shock anywhere. The recommendations are, therefo
of importance to many thousands of workmen:

In case of gas poisoning, remove victim at once from the gaseo
atmosphere. Carry him quickly to fresh air and immediate
give manual artificial respiration. Do not stop to loos
clothing. Every moment of delay is serious.

In case of electric shock, break electric current instantl
Free the patient from the current with a single quick motio

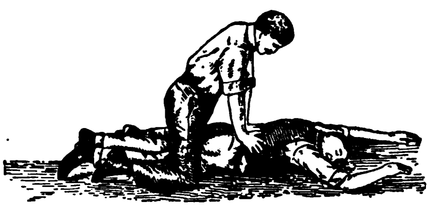
using any dry non-conductor, such as a newspaper, clothing, rope, or board, to move patient or wire. Beware of using any metal or moist material. Meantime have every effort made to shut off current.

Attend instantly to the victim's breathing. If the victim is not breathing, he should be given manual artificial respiration at once. If the patient is breathing slowly and regularly do not give artificial respiration, but let nature restore breathing unaided.

If patient is unconscious, even if he appears dead, lay him on his belly with arms extended forward, turn his face to one side, remove false teeth, tobacco, etc., from his mouth and draw his tongue forward.

Kneel, straddling patient's thighs, facing his head, and resting your hands on his lowest ribs. Swing forward and *gradually* bring weight of your body upon your hands and thus upon patient's back, then immediately remove pressure by swinging

Inspiration; pressure off.



Expiration; pressure on.

backward. Repeat this movement about twelve times per minute without interruption for hours if necessary, until breathing has been started and maintained (see illustrations).

In gas cases, give oxygen. If the patient has been a victim of gas, give him pure oxygen, with manual artificial respiration. The oxygen may be given through a breathing bag from a cylinder having a reducing valve, with connecting tubes and face mask, and with an inspiratory and an expiratory valve, of which the latter communicates directly with the atmosphere.

No mechanical artificial resuscitating device **should b**
unless one operated by hand that has no suction **effect**
lungs. Use the SCHAEFER or prone pressure **method of ar**
respiration. Begin at once. A moment's **delay is s**
Continue the artificial respiration. If necessary, **conti**
hours or longer without interruption until natural **breath**
restored. If natural breathing stops after **being res**
use artificial respiration again.

Do not give the patient any liquid, until he is fully **cons**
Give him fresh air, but keep his body warm. **Send fo**
nearest doctor as soon as accident is discovered.

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